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WELCOME

ON 6 AUGUST 1945 at 8.15am, an atomic bomb struck Hiroshima, Japan. Three days later, the US would drop a second on Nagasaki. It was the first, and last, time that nuclear weapons would be used in war. Soon after, a scientist who had helped design the atomic bomb, Dr Harold Jacobsen, would tell *The Washington Post* that "nothing would grow in Hiroshima for the next 70 years". He was wrong.

As soon as one month after the impact, red canna flowers – pictured on our cover – burst into bloom. The flowers would become a symbol of hope for the survivors. Today, 70 years later, Hiroshima thrives. Find out how life returned to the city on p32.

Also this month, Curiosity has spent three years on Mars. The bot has been busy: taking selfies, zapping rocks with lasers and even doing some science. Follow its journey so far on p64. Back on Earth, NASA scientists are planning another mission. Their goal is to answer one of cosmology's biggest mysteries: is there alien life in our Solar System? Find out about this and other cosmic conundrums on p48.

Finally, if you're planning a holiday this summer, take a glance at the future of flight on p42. From supersized seaplanes to a successor for Concorde, commercial flight is about to get a lot better. Enjoy!

Daniel Bennett

Daniel Bennett, Acting Editor

PS Don't miss our September issue, on sale 20 August 2015

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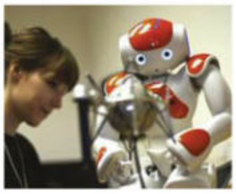
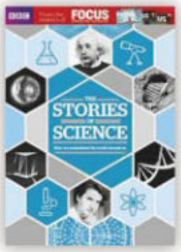
THIS MONTH WE...

...got our hearts monitored as we zoomed round a track with a stunt driver at the Goodwood Festival Of Speed. We didn't scream... honest! Find out more on our website.

...paid a visit to the Royal Society Summer Science Exhibition. Highlights this year included a 3D-printed replica of Richard III's skeleton, and this rather friendly-looking robot.



...chatted with Frank Wilczek about the beauty in physics. Read our interview with Frank on p98, in which we discuss the symmetry found in life and the Universe.



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APPEARING IN THIS ISSUE...

Lilian Anekwe

E-cigarettes are becoming ever more popular on our high streets, but are they safe? Lilian, the consumer health editor of *The BMJ*, finds out if we can breathe easy on p58.

Stuart Clark

Stuart is an astronomy writer and author of *The Unknown Universe*, published in September 2015. On p48, he reveals the mysteries that continue to baffle astronomers.

Adam Hart

Adam is a BBC presenter, lecturer and bug-botherer. On p56 he tells us why we should be kinder to the wasps this summer – even if they do invade our picnics and barbecues.

Graham Warwick

As technology editor at *Aviation Week*, Graham was just the chap to take a look at cutting-edge designs for the planes of the future. Turn to p42 to find out what we can look forward to.

WANT TO SUBSCRIBE? Turn to p30 to get five issues of *BBC Focus* for just £5

SUBSCRIBER BONUS On p30, **Darren Naish** stomps back through time to tell us more about dinosaur extinction

COVER: ANDY POTTS

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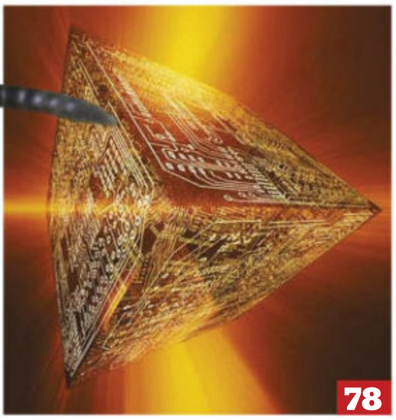

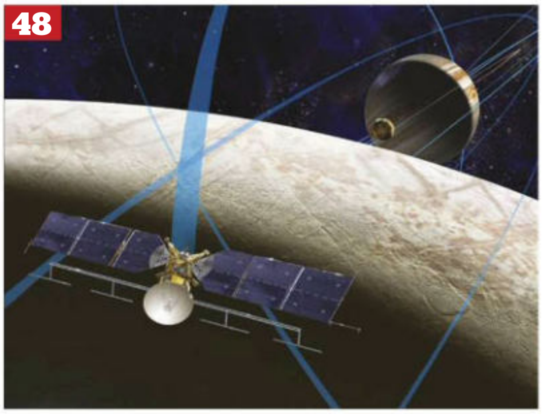

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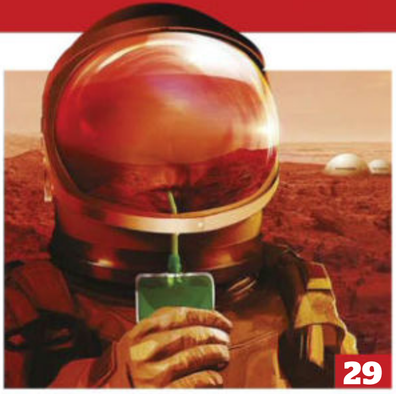
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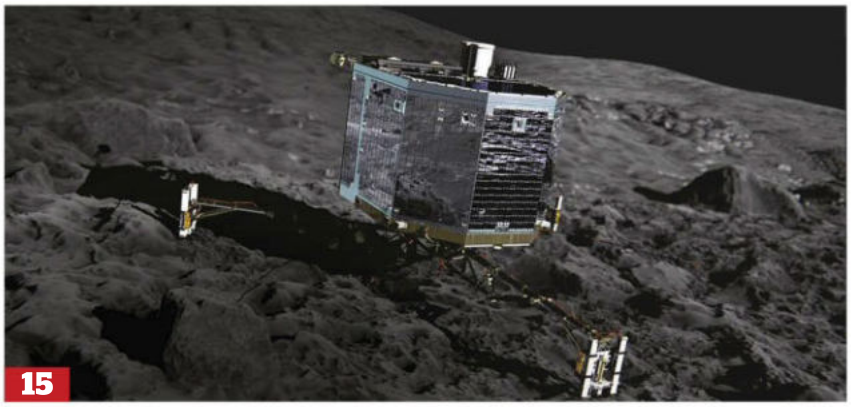
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BBC Science Focus (ISSN 0966-4270) (USPS 015-160) is published 13 times a year (monthly with a Summer issue in July) by Immediate Media Company, Bristol, 2nd Floor, Tower House, Fairfax St., Bristol BS1 3BN. Distributed in the US by Circulation Specialists, LLC, 2 Corporate Drive, Suite 945, Shelton, CT 06484-6238. Periodicals postage paid at Shelton, CT and additional mailing offices. POSTMASTER: Send address changes to *BBC Science Focus*, PO Box 37495, Boone, IA 50037-0495.

Awe-inspiring images from the world of science

MegaPixel

Winged wonders

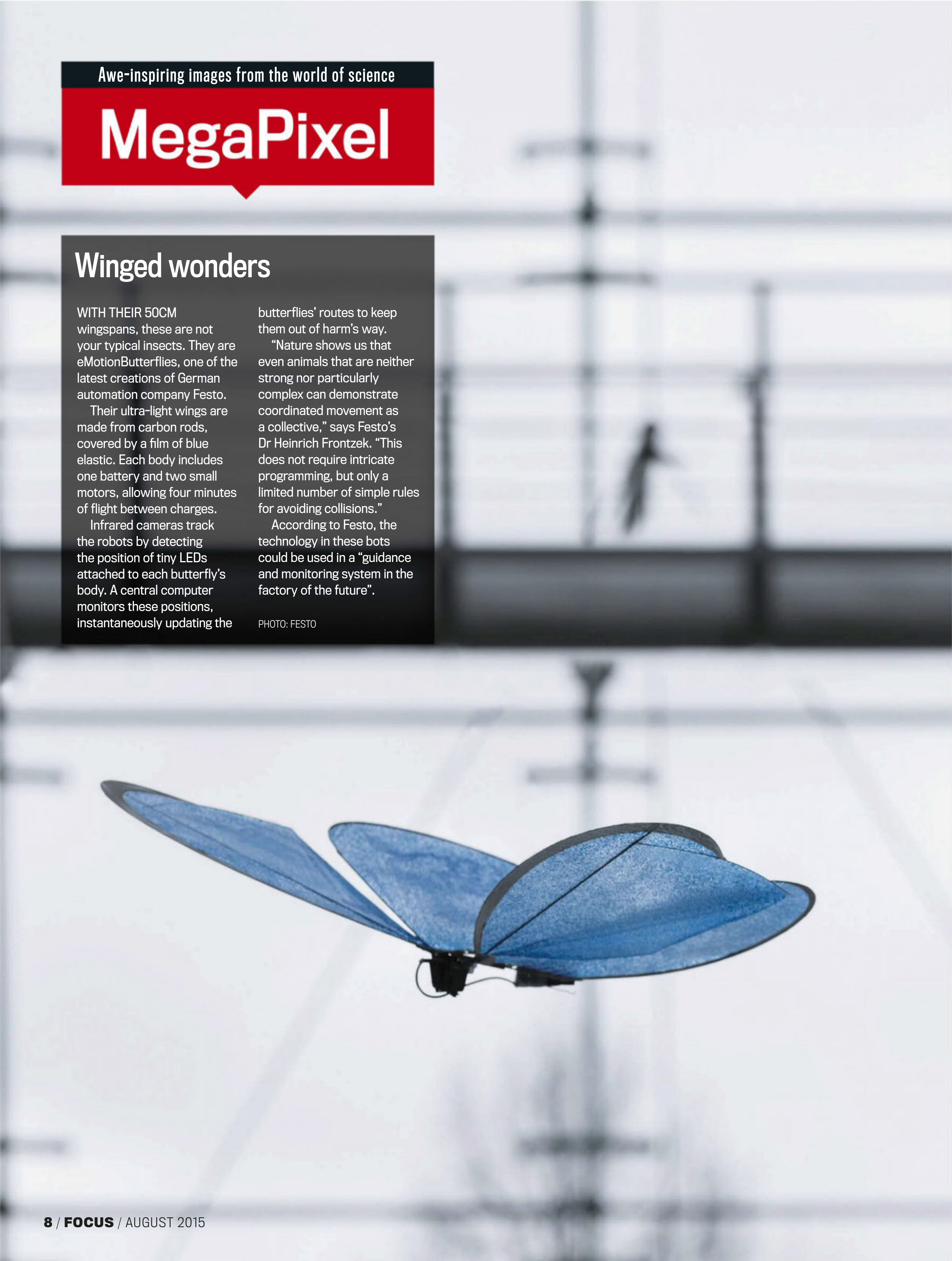
WITH THEIR 50CM wingspans, these are not your typical insects. They are eMotionButterflies, one of the latest creations of German automation company Festo.

Their ultra-light wings are made from carbon rods, covered by a film of blue elastic. Each body includes one battery and two small motors, allowing four minutes of flight between charges.

Infrared cameras track the robots by detecting the position of tiny LEDs attached to each butterfly's body. A central computer monitors these positions, instantaneously updating the butterflies' routes to keep them out of harm's way.

"Nature shows us that even animals that are neither strong nor particularly complex can demonstrate coordinated movement as a collective," says Festo's Dr Heinrich Frontzek. "This does not require intricate programming, but only a limited number of simple rules for avoiding collisions."

According to Festo, the technology in these bots could be used in a "guidance and monitoring system in the factory of the future".



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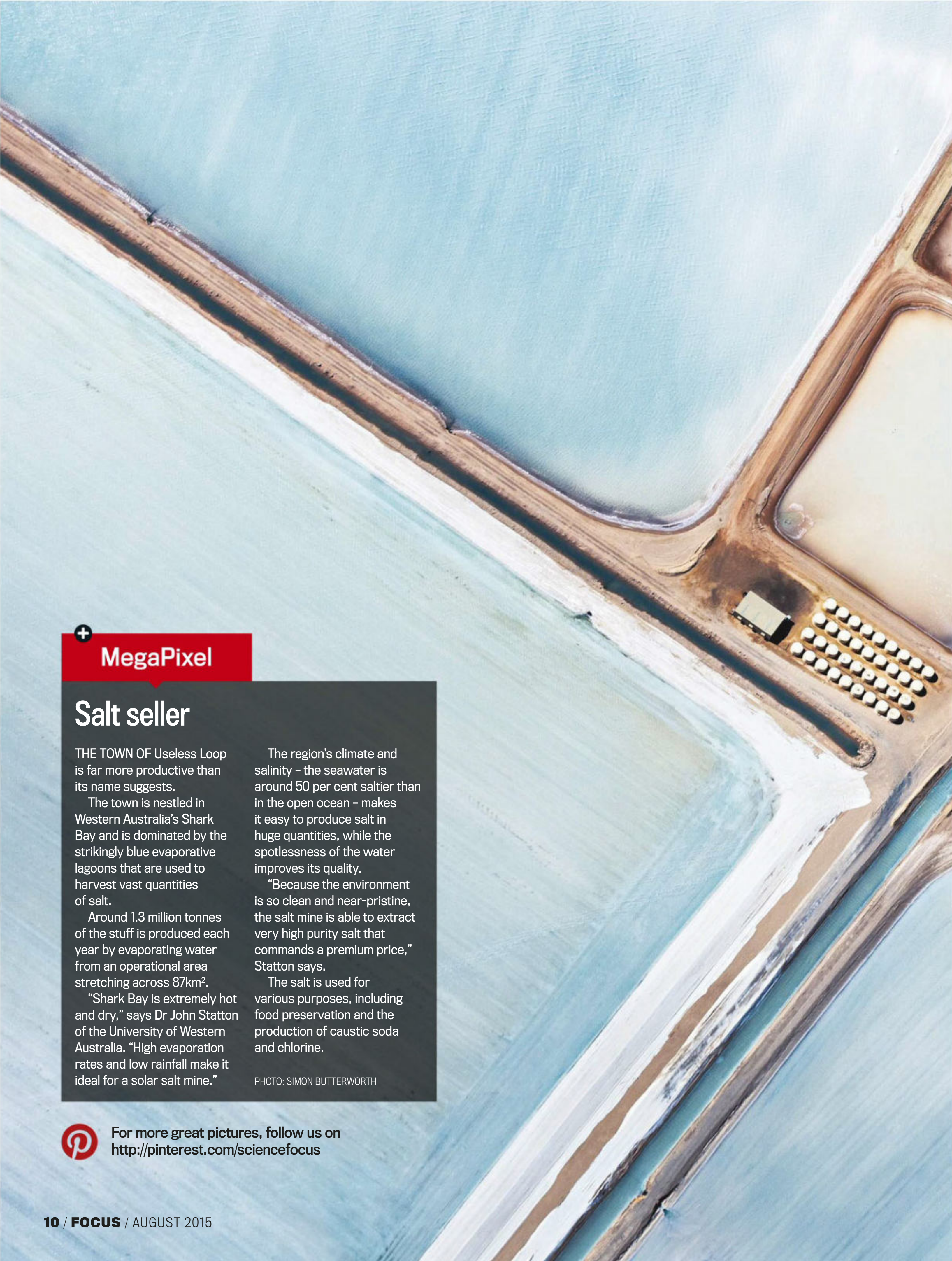

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Salt seller

THE TOWN OF Useless Loop is far more productive than its name suggests.

The town is nestled in Western Australia's Shark Bay and is dominated by the strikingly blue evaporative lagoons that are used to harvest vast quantities of salt.

Around 1.3 million tonnes of the stuff is produced each year by evaporating water from an operational area stretching across 87km^2.

"Shark Bay is extremely hot and dry," says Dr John Statton of the University of Western Australia. "High evaporation rates and low rainfall make it ideal for a solar salt mine."

The region's climate and salinity – the seawater is around 50 per cent saltier than in the open ocean – makes it easy to produce salt in huge quantities, while the spotlessness of the water improves its quality.

"Because the environment is so clean and near-pristine, the salt mine is able to extract very high purity salt that commands a premium price," Statton says.

The salt is used for various purposes, including food preservation and the production of caustic soda and chlorine.

PHOTO: SIMON BUTTERWORTH

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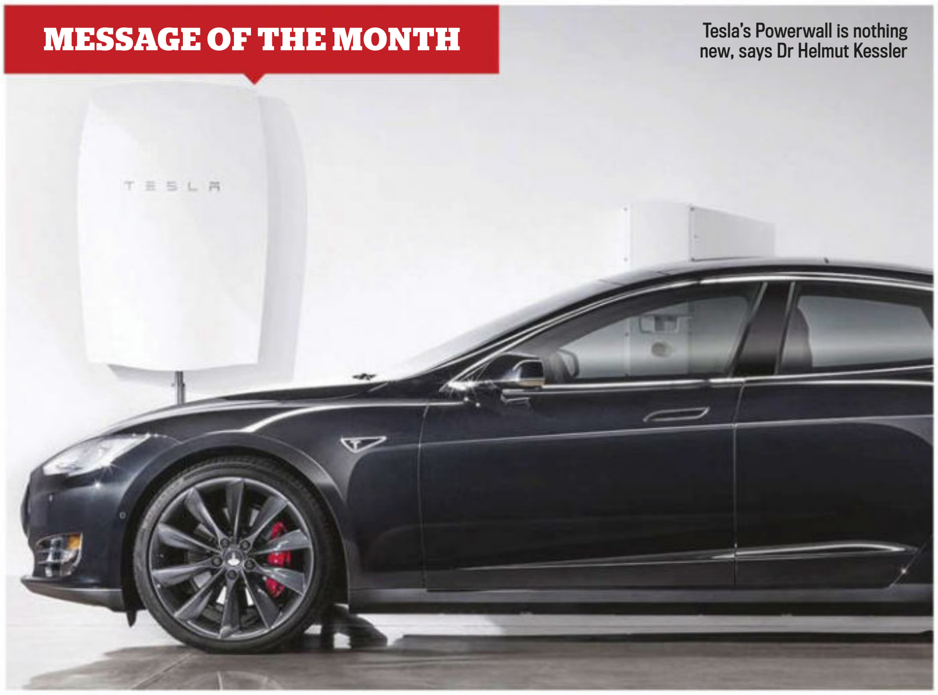
MESSAGE OF THE MONTH



Tesla's Powerwall is nothing new, says Dr Helmut Kessler

We had backup power before it was cool

READING YOUR ARTICLE about the Tesla Powerwall (July, p79) made me remember that about a century ago my family used a setup similar to the Tesla Powerwall.

On my grandmother's side, the family owned a windmill in northern Germany. Being sparsely populated around the time of the Great War, it was not common to be connected to the electricity grid when you lived in the countryside. My great-grandfather, being interested in technology, acquired a generator and some large batteries (my grandmother could not remember anything about capacity but remembered that they were big), which he charged with the wind power generated by the mill. A cable run across the yard enabled the family to enjoy electric light in the farmhouse, which was particularly pleasing during the long cold winter nights. During the late 1920s, the area was connected to the grid and the equipment sold or scrapped as it was no longer needed. The windmill itself still exists and I have fond memories of climbing to the very top to enjoy the view.

On reading the Tesla article, I couldn't help thinking, 'This has been done before!'

Dr Helmut Kessler

Write in and win!

The writer of next issue's Message of the Month wins a pair of smartphone compatible AKG Y50 headphones, worth £79.99. The lightweight design ensures maximum comfort, while a 3D-axis folding mechanism makes these headphones easy to slip into your bag for enjoying music when out and about. **eu.akg.com**

Time trouble

There's a problem with the idea of time travel (Summer, p40) that I've never heard discussed: how would you navigate to your destination?

Everything in space is moving at great speed, including the surface of the Earth. A time jump of even a few seconds would leave you somewhere other than where you started – a few hours could leave you stranded in deep space.

Sydney Barber, Inverness

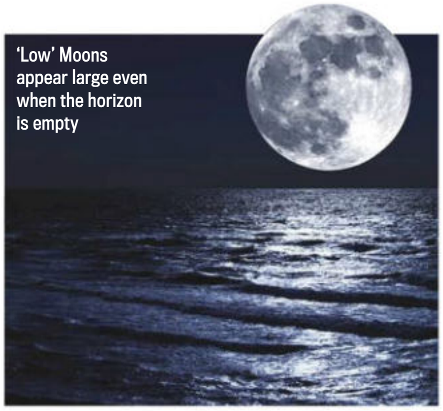
John Gribbin replies: *This is a very good point which many science fiction stories miss. A time machine would have to be a space machine as well – like the TARDIS (Time And Relative Dimensions In Space). See Christopher Priest's story* The Space Machine *for more on this idea.*

When the Moon hits your eye...

In the Summer issue's 'Reply' section, David Canning wondered why the Moon appears larger at the horizon, even at sea. Research into visual perception in recent years has uncovered many distortions or illusions in our perception of the relative size or distance of objects.

It is assumed that these were caused, or at least allowed to persist, by evolutionary selection because they had adaptive advantages. For our distant ancestors, attack from the air was fairly unlikely, whereas objects close to or on the horizon were much more likely to be predator or prey. It was therefore advantageous if anything appearing here was allowed to attract more attention.

Simon Raggett, London



'Low' Moons appear large even when the horizon is empty

PHOTO, TESLA, REACTION ENGINES, ISTOCK X2

Reaction's hypersonic engine will make its debut next year

Reactionary reply

In the Summer issue of *Focus* I read with interest the Message of the Month entitled 'Hypersonic Hopes'. I say 'with interest' because I was the lecturer that Mr Goodison had listened to back in 2012. In the talk that he heard, I told the audience about the company Reaction Engines Ltd, based near Oxford, whose designers were on the cusp of producing a radical new aircraft engine that could power a plane with 300 passengers from Europe to Australia in just over four hours, at hypersonic speeds of Mach 5.

The situation has since moved on. The European Space Agency and the UK Space Agency are now partially funding Reaction Engines' research and the prototype engine is currently being built, ready to be tested in 2016. The technology will be initially incorporated into two vehicles. The first to fly will probably be a European Space Shuttle that takes off and lands horizontally; the second application will be the aforesaid hypersonic passenger aircraft. Exciting times, with the potential to radically change both spaceflight and terrestrial aviation.

Exciting times, that is, provided that governments and industry have the foresight to support their efforts. If they don't, then we'll still be travelling at the same speeds as we were 50 years ago – Concorde excepted, of course.

Pete Finlay

Long live cash!

In response to Bill Thompson's article 'A cash-free world' (April, p79), I'd like to point out the great difference between cash and plastic money: plastic isn't actually yours. Cash is physically yours – you can use it at will. However, it's naive to think that you actually own your plastic money. If the bank or the government decide that you owe them, try getting something to eat with plastic money!

Paying with plastic means that you live your life only on condition that the bank allows you to. To me this a major issue and I would never consider the weight of coins to be of greater importance.

Kostas Kalimaftsis, Greece

One small step for a man...

I read the article regarding 'true colours' in Summer issue of *Focus* with great interest. I am severely colour blind, which can cause interesting observations.

A few years ago, I was walking along a country lane with a friend when they exclaimed, "Look at all the red berries on that tree!" I could see the tree, but not a single red berry. I continued to walk toward the tree when, suddenly, there were all the red berries. This surprised me so, I took a couple of steps back and the berries disappeared. I quickly realised I could make the berries come and go with just a small step.

It took me 72 years to make that discovery! I have often wondered what it must be like to have 'full colour' vision.

Emrys Consett, County Durham

Go on, get counting...

Clearing up the Milky Way

I noticed that in the Summer issue of *Focus*, two separate articles give wildly different estimates as to the number of stars in the Milky Way. On p22, the article 'The Milky Way weighed more accurately' states there are "roughly 100 billion stars". But on p80, the jargon buster that accompanies the article 'Understand dark matter in 10 minutes' says that there are "around 200 billion stars" in the Milky Way.

I understand there must be a high level of uncertainty when it comes to estimating the number of stars, but surely not as much as 100 per cent?

Frederico Tak, Oxfordshire

The fact is, scientists just don't know how many stars there are in the Milky Way. It's thought that there are at least 100 billion, but there may be as many as 400 billion.

Oops!

- In 'Reply', issue 283, we wrongly described Operation PLUTO as supplying fuel to the UK in WWII. In fact, it took fuel from the UK to Allied forces in France after D-Day.

FOCUS
SCIENCE AND TECHNOLOGY

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Annual subscription rates (inc P&P):
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DISCOVERIES

News and views from the world of science

EDITED BY
JASON GOODYER

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GOODBYE TO THE ANIMALS

Are we in the middle of a mass extinction event – and what can we do to stop it?

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HOW WE LEARN

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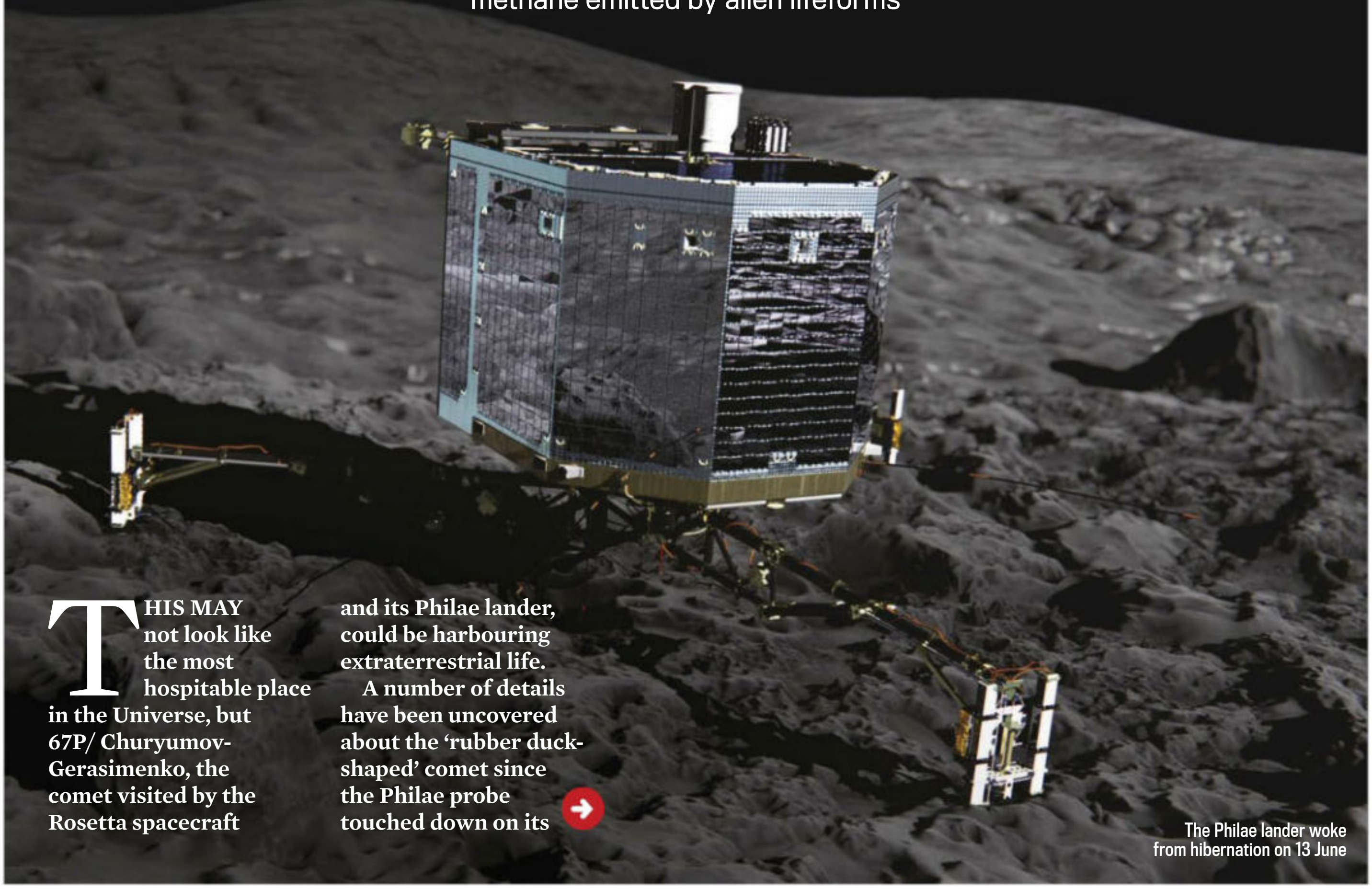
FLIGHT ON MARS

NASA announces plans to send drones to survey the Martian surface

THE BIG STORY

IS THERE
LIFE ON COMET 67P?

Philae lander will hunt for signs of methane emitted by alien lifeforms



The Philae lander woke from hibernation on 13 June

PHOTO: NASA/ESA

THIS MAY not look like the most hospitable place in the Universe, but 67P/ Churyumov-Gerasimenko, the comet visited by the Rosetta spacecraft and its Philae lander, could be harbouring extraterrestrial life.

A number of details have been uncovered about the 'rubber duck-shaped' comet since the Philae probe touched down on its

Rosetta scientists discussed the mission's latest developments at the Paris Air And Space Show on 17 June

surface last November. It appears to be covered with huge sheets of ice and frozen, flat-bottomed crater lakes, all overlain with organic debris.

Now, Max Wallis, from the University of Cardiff, and Chandra Wickramasinghe, Director of the Buckingham Centre for Astrobiology, argue that this mixture of ice and organic material could provide an ideal environment for the existence of alien microorganisms. "Rosetta has already shown that the comet is not to be seen as a deep-frozen inactive body, but supports geological processes and could be more hospitable to micro-life than Earth's own Arctic and Antarctic regions," said Wallis. "We consider it highly likely that comets like 67P harboured life in the past and may, even to date, keep viable life in a deep-frozen state."

Any microorganisms that might be present on 67P would require liquid water bodies to exist on the comet, and could also inhabit cracks on the ice created by forces that the oddly shaped, asymmetric comet body generates as it spins. Some types of microorganisms are particularly good at adapting to these conditions and could be active at temperatures as low as –40°C.

Sunlit areas of 67P approached this temperature last September, when the comet was at a distance of some 500 million kilometres from the Sun. As it travels to its closest point to the Sun, at 195 million kilometres, the temperature will rise and any microorganisms that are present would become increasingly active.

The team says the abundance of complex organic molecules found on the comet's surface by the lander Philae also point to the existence of life.

"If they can get the lander Philae working fully, its investigation of methane will help distinguish biomethane [methane produced by life forms] from other carbon-containing gases that could be released simply by solar radiation on the complex carbon compounds," said Wallis. "Investigation by the Rosetta instruments will help too, though the gases will be a little degraded by the time they reach the orbiting craft."

TIMELINE

A brief history of the Rosetta mission

2004

Rosetta launches and commences its 6.3 billion kilometre, 10-year journey towards comet 67P. The craft is programmed to go into hibernation on reaching its destination.

JAN 2014

Rosetta receives a signal to wake up. Soon afterwards, it sends its first images of the comet back to Earth. Scientists are surprised by the comet's unusual 'rubber duck' shape.

NOV 2014

Rosetta sends Philae, its lander, towards the comet. Philae sends back reams of unprecedented data and images back to Earth, but having landed in shadow, powers down after just 60 hours.

JUN 2015

With the Sun back in the sky from Philae's point of view, the lander powers back up on 13 June and resumes communication with Rosetta. New objectives now await...

GOOD MONTH/ BAD MONTH

It's been good for:

BACON LOVERS

IF YOU LOVE chowing down on a bacon sarnie but aren't so fond of the effect your culinary habits have on your waistline, you may be in luck. A team of scientists in South Korea has used gene-editing technology to create a new breed of 'double-muscled' pigs. The porkers could be used to make extra-lean bacon.

FANS OF CAT VIDEOS

IT TURNS OUT all that time we have spent watching funny felines on YouTube wasn't wasted after all. A study at Indiana University has found that watching Maru, Grumpy Cat and Lil Bub boosted viewers' energy and reduced levels of anxiety, sadness and stress. The results suggest that online videos may one day be used as a form of low-cost pet therapy.

It's been bad for:

BOYS

WHEN TIMES ARE tight, it's better to be female. Researchers in the US have found that in time of economic hardship parents are more likely to spend a larger proportion of their money on daughters. The effect is more pronounced when the daughters are getting closer to childbearing age, suggesting the parents want grandchildren, they say.

NIGHT OWLS

THOSE WITH POOR sleep habits such as inconsistent bedtimes and short sleeping periods are more likely to succumb to impulsive desires, inattentiveness and questionable decision making, a US study has found. The effect is thought to be due to depleted energy reserves making us more likely to plump for the easier option or task.

PHOTO: NASA, ESA X2, ISTOCK X2

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Can we stop mass extinction?

DAVID SHUKMAN

The science that matters

A TEAM OF researchers has recently confirmed what has been suspected for some time about the world's wildlife: that we are witnessing a sixth mass extinction.

Everything from chopping down the rainforests to polluting the oceans and rivers is driving losses on an accelerating scale. And among the most vulnerable are the primates – especially if they live in poor countries where people are hungry.

A recent filming trip to Madagascar brought home to me how the famous lemurs of that remarkable island are on the brink of extinction. One image that will haunt me forever is of a baby lemur, bug-eyed and confused, crawling over the body of its dead mother moments after she had been shot by poachers. Hunting is exacting a terrible toll, as is the clearing of the trees to make way for farmland.

But there are brave efforts at conservation. Some key habitats for lemurs have been ring-fenced by the Madagascar government. International charities are helping local people work as guides rather than hunters – and it's widely accepted that without the support of local communities, the animals have no chance.

Lemurs from Madagascar are hunted for their meat

Scientists have two important roles to play. The first is to map and understand where and how the lemurs live. Despite years of study – and high profile DreamWorks movies – there is still a lot to learn about the diet, breeding habits and social structure of lemurs. Gathering these facts could influence government policy.

But science is important in another way too: simply having a presence in the rainforests helps keep the lemurs safe. In one area in the east of Madagascar, we trekked through steep jungle to a rest house used by young researchers from Italy, the US and the UK.

With teams constantly scouting for lemurs, and keeping track of their movements, life is made difficult for anyone thinking of slipping into the area for hunting or logging. As one expert put it, just having researchers in the forest acts as a deterrent.

But everyone realises the challenge. With Madagascar's population booming, and nearly everyone living on less than the equivalent of $2 a day, the days of lemurs thriving in the wild may be numbered.

DAVID SHUKMAN is the BBC's Science Editor. @davidshukmanbbc

WHO'S IN THE NEWS?

Kevin Smith

Bioethicist at Abertay University in Dundee

What's he done?

Smith recently called on all 18-year-old men to have their sperm frozen if they were thinking about starting a family in later life. He says that this would prevent their children from having genetic disorders.

How does that work?

The sperm cells of older men contain more genetic mutations than those of younger men. While most of these mutations have little or no impact, Smith reckons that older fathers could be running a higher risk of having children with health issues such as autism and schizophrenia.

Is he right?

Well, his comments have proven pretty controversial. While it is generally accepted that the risks of certain genetic disorders increase with the age of the father, some experts say the effect is minimal. Smith thinks that sperm freezing should be available on the NHS. However, others have said that sperm from the majority of men doesn't freeze well, so most older couples would need to undergo IVF treatment regardless.

PHOTO: BENARD CASTELEIN/NATUREPL.COM

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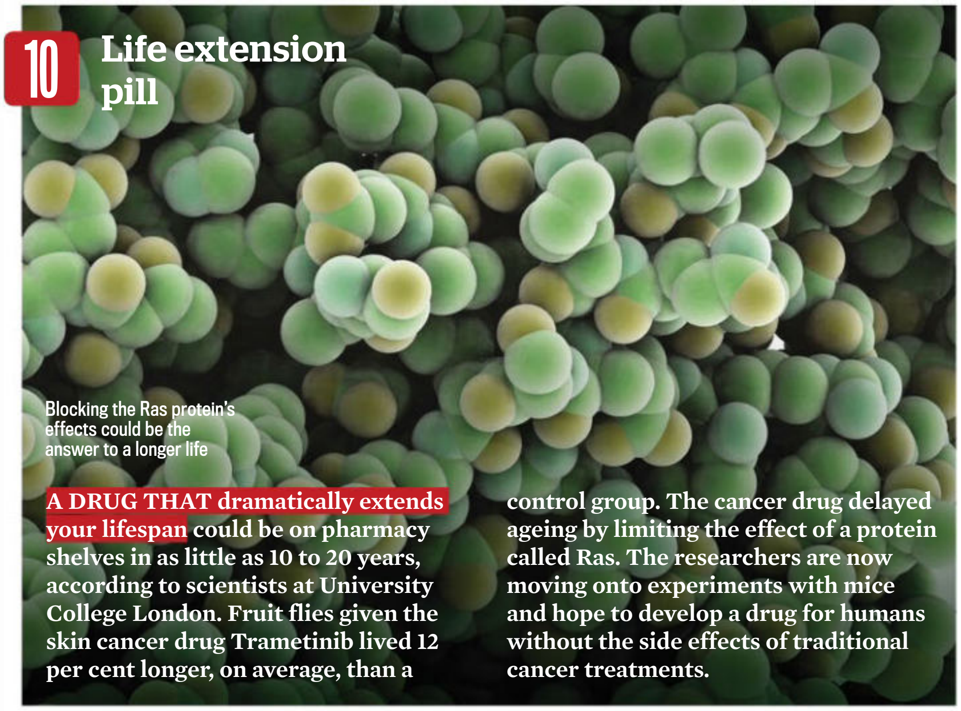
10 DISCOVERIES THAT WILL SHAPE THE FUTURE

BY GRAHAM SOUTHORN

10 Life extension pill



Blocking the Ras protein's effects could be the answer to a longer life

A DRUG THAT dramatically extends your lifespan could be on pharmacy shelves in as little as 10 to 20 years, according to scientists at University College London. Fruit flies given the skin cancer drug Trametinib lived 12 per cent longer, on average, than a control group. The cancer drug delayed ageing by limiting the effect of a protein called Ras. The researchers are now moving onto experiments with mice and hope to develop a drug for humans without the side effects of traditional cancer treatments.

9 Water-saving grass

US GOLF COURSES need 750 billion gallons of water every year to look their best. Using wastewater instead of clean water on links and other sports fields is the way forward. But wastewater contains salt, which plants don't like. Researchers at Rutgers University tested 142 varieties of perennial ryegrass, bred to have different genetic traits. The results showed it's possible to selectively breed grass to produce varieties that have a high tolerance to salt.

Some grasses turn brown when in contact with salts, while other strains retain their green colour

8 Artificial mosquito blood

PUTTING OUT FOOD for mosquitoes might not seem like the smartest idea. Yet artificial blood developed at the University of Kentucky may prove hugely important in the fight against mosquito-borne diseases like malaria, dengue and yellow fever. The 'blood' can be laced with a mozzie-sterilising bacterium and put out as a free banquet.

Your days are numbered, Mrs Mosquito...

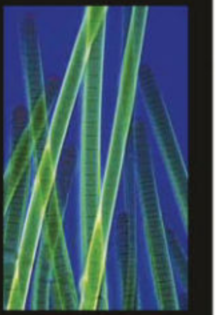
7 Evaporation engine

NATURE'S BIGGEST UNTAPPED power source could be evaporation. Now, Columbia University scientists are building engines and generators that harness this renewable resource. They use *Bacillus* spores, which expand and contract as they absorb moisture from the air. This movement can then be used to drive turbines. Find out more at bit.ly/evaporation_power

This little car is powered by the evaporation of water

6 Transplantable body clock

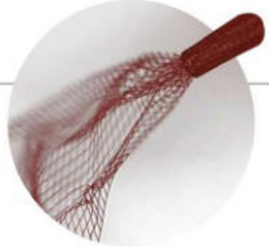
CIRCADIAN RHYTHMS HELP your body regulate time, but they can get out of sync. A genetically engineered, transplantable body clock could help treat problems like jet lag. Harvard University researchers extracted a protein circuit from cyanobacteria, which has a natural rhythm, and transplanted it into *E. coli*, which doesn't. The *E. coli* could then 'blink' by switching a fluorescent marker on and off every 24 hours.



Cyanobacteria has a natural rhythm

PHOTO: SCIENCE PHOTO LIBRARY X2, STACY BONOS, MISSOURI UNIVERSITY, BINGHAMTON UNIVERSITY, UNIVERSITY OF BRISTOL, COLUMBIA UNIVERSITY, ISTOCK

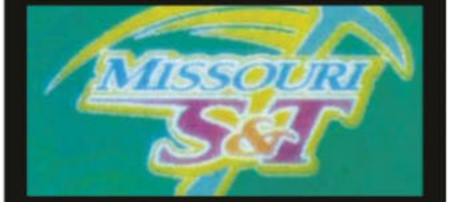
5 Brain mesh



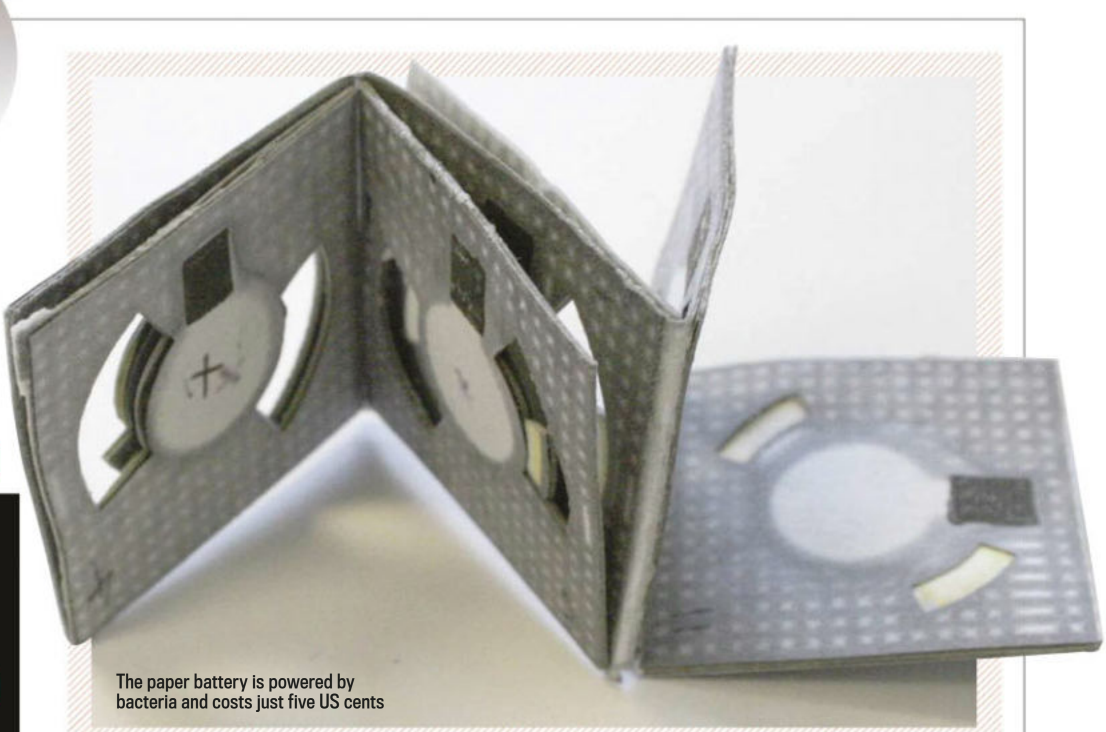
BEFORE YOU CAN create a cyborg, you need a means of carrying electrical signals to and from the brain. Now, Harvard scientists have successfully injected an electronic mesh into the brain of a mouse. The mesh was initially rolled up in a syringe, but unfurled and melded with brain tissue once injected. In future, it may help treat neurodegenerative disorders in humans.

4 Invisible security tags

A TEAM AT Missouri University has created microscopic colour images by making tiny perforations in a multi-layered material. The tech could be used for creating advanced security tags that are difficult to replicate.



This logo measures just 50 micrometres across



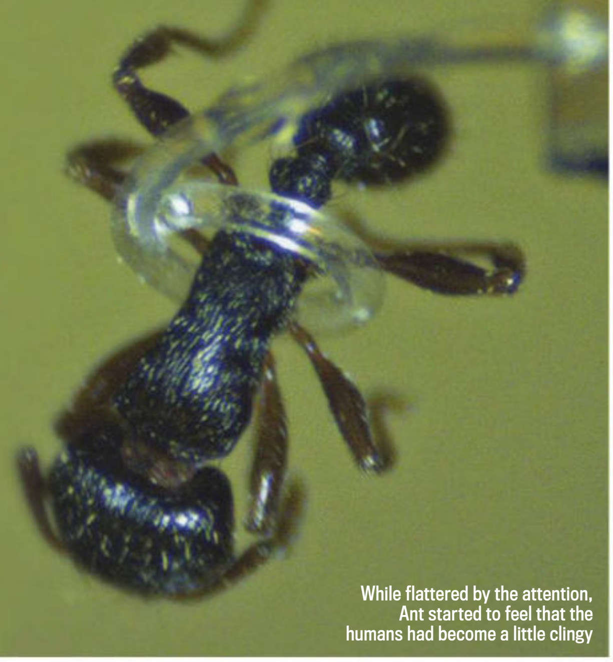
The paper battery is powered by bacteria and costs just five US cents

3 Paper battery

A PAPER BATTERY constructed using origami techniques has been unveiled at Binghamton University in New York State. The battery requires just one drop of bacteria-containing liquid such as wastewater. It generates energy from the respiration of the microorganisms present in the water. It supplies only a few microwatts, but that's enough to power paper biosensors that have been developed to detect diseases like HIV and *E. coli* in developing countries.

2 Robot tentacles

PICKING UP TINY, fragile objects without causing damage can be something of a challenge for a set of robot pincers. So a spiralling tentacle developed at Iowa State University could be just the job for manipulating human tissue or blood vessels. The tentacle is an 8mm long tube with a diameter of less than 0.4mm. It is made of a class of rubbery polymers called elastomers. Air pumped into the tube causes it to coil, allowing it to gently squeeze the object it's picking up without causing any damage.



While flattered by the attention, Ant started to feel that the humans had become a little clingy

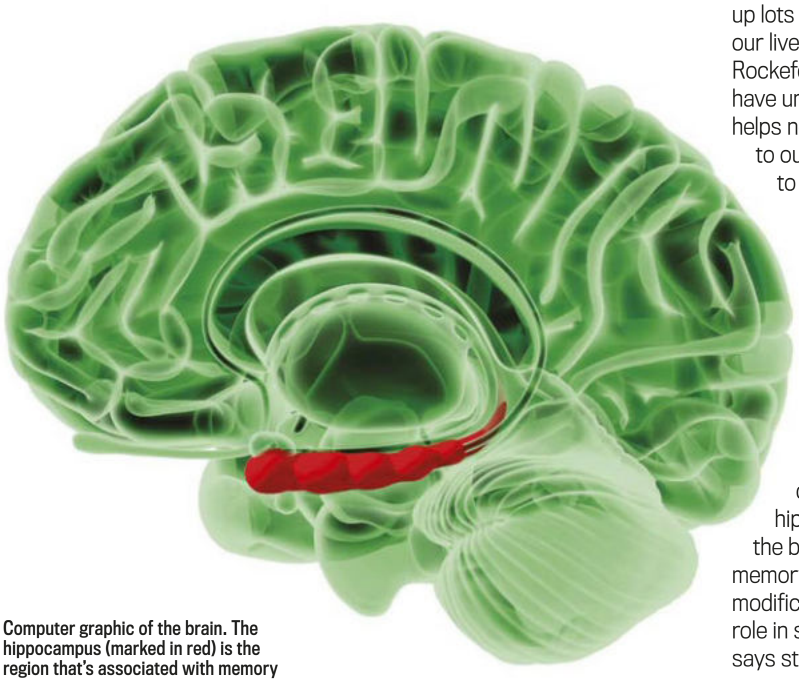
1 Smart camouflage

SQUID AND OCTOPUSES use cells called chromatophores to create colours and patterns on their skin. Now, researchers at the University of Bristol have made a material that mimics this effect. Soldiers could use the fast-changing, adaptive camouflage on covert missions. It's made from a rubbery material that can be electrically controlled.

Three artificial chromatophores created by the team

NEUROSCIENCE

Brain's learning mechanism uncovered



Computer graphic of the brain. The hippocampus (marked in red) is the region that's associated with memory

WHETHER YOU'RE LEARNING how to swim, how to speak a second language or how to play an instrument, we humans can pick up lots of skills over the course of our lives. Now, researchers at The Rockefeller University in New York have uncovered a mechanism that helps neurones to adapt according to our experiences, allowing us to learn new things.

It all comes down to proteins called histones. These support DNA and help to control how genes are expressed. The team found that the ability of neurones to form new links is related to the loss and replacement of a histone called H3.3 in the hippocampus, the region of the brain associated with memory. "Histones and their modifications play an important role in switching genes on and off," says study author Dr C David Allis. "This research uncovers a mechanism, involving one slightly modified histone, that makes learning possible by facilitating the genetic changes necessary for neurones to form connections."

By measuring the histone levels in the brains of mice and in postmortem human samples, the researchers found that levels of H3.3 increase with age. And rather than remaining in place on DNA, it is constantly recycled. They also found that when the mice were raised in a more stimulating environment with a running wheel and lots of toys, the rate of this recycling was increased.

"When we put an end to histone turnover in adult mice, we found it disrupted normal gene expression patterns associated with [brain] plasticity, and as a result, impaired the animals' ability to learn," explains researcher Ian Maze. "They had greater difficulty, for instance, distinguishing familiar objects from new ones."

MEDICINE

Cannibalistic tribe provide brain disease breakthrough

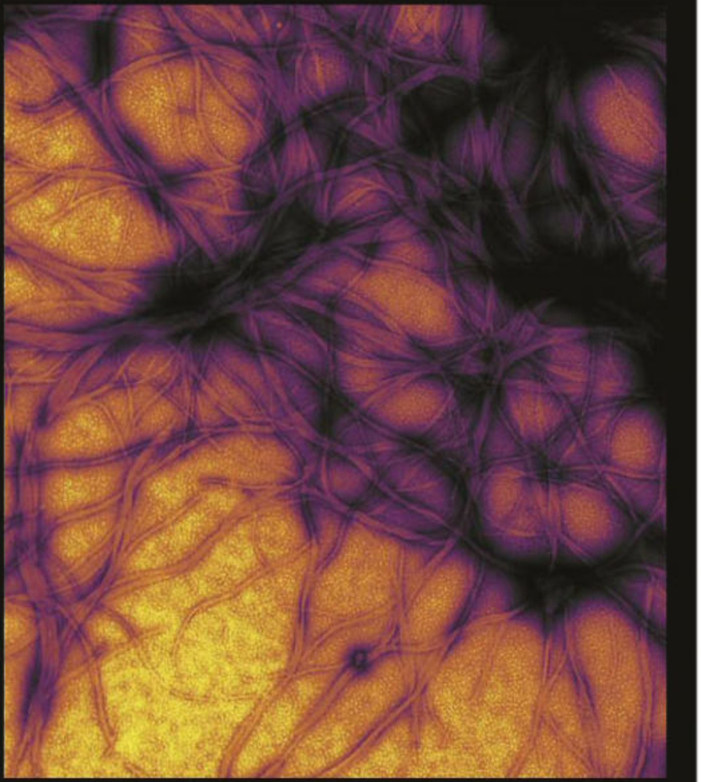
A PAPUA NEW Guinean tribe famous for eating human brains may be helping to shed light on neurodegenerative diseases such as Alzheimer's, Parkinson's and Creutzfeldt-Jakob Disease (CJD).

Surviving members of the Fore tribe have developed a genetic resistance to kuru, a CJD-like disease caused by the practice of consuming dead relatives during funeral rituals, a team at UCL has found. When the practice was at its highest during the 1950s, the disease claimed the lives of one in 50 people.

Like CJD and some forms of dementia, kuru is caused by 'prions' – a type of protein that can change shape and clump together to form fibres that can damage the normal tissue of the brain. But the team found that evolutionary changes in the so-called prion protein gene gave the survivors genetic protection against kuru. The gene in question causes alterations in just one of the 253 amino acids that make up the prions, but that change seems to be enough to grant protection.

The researchers then genetically engineered mice to carry the same change, and found that they were 100 per cent resistant not only to kuru but also to all forms of CJD, including the form known as 'variant CJD', caused by human infection with BSE.

"This is a striking example of Darwinian evolution in humans – the epidemic of prion disease selecting a single genetic change that provided complete protection against an invariably fatal dementia," says team leader John Collinge. "Much work is now ongoing in the unit to understand the molecular basis of this effect, which we expect to provide key insights into how seeds of other misshapen proteins develop in the brain and cause the common forms of dementia, thereby guiding us to new treatments in the years ahead."



Prion proteins can clump together as fibres, interfering with normal brain function

PHOTO: SCIENCE PHOTO LIBRARY, NIAID

INSIDE SCIENCE

ROBERT MATTHEWS

Maths can explain why 'silly season' formulas are complete nonsense

FORGET BARBECUES AND storms: nothing proclaims summer quite as reliably as 'silly season' stories. And they don't come much sillier than those proclaiming that 'Scientists have found the formula for the perfect…', well, you name it. Cheese on toast, relationships, handshakes – the list grows longer every year.

Everyone with an IQ exceeding their shoe size knows these stories are twaddle dreamed up by PR outfits. Sometimes they're put together with help from real scientists who really should know better. Some years back, I was offered a tidy sum of money to devise a 'formula' for the perfect loo brush or something. As it was clearly going to end up as the formula for appearing perfectly ridiculous, I declined.

I've since discovered that silly formulas aren't the preserve of desperate PR people. Over 150 years ago, the brilliant Victorian polymath Francis Galton devised what he regarded as the scientific formula for the perfect cup of tea. Here it is: $(C+n)t = C+ne$, where C is the volume of tea, n the number of ounces of tea used, t the temperature of the teapot and e the difference between the temperature of the water and the teapot.

I find it hard to believe Galton brewed this stuff up, as one glance shows it must be nonsense. That's because it breaks a law even more fundamental than the laws of physics: dimensional homogeneity.

Despite the name, the idea is very simple. Every physical quantity – area, velocity, force and the rest – is expressed in units known technically as dimensions, such as length, time and mass. They're the building blocks from which everything can be constructed.

For example, we measure area in units like square metres or square kilometres, so area is said to have 'dimensions' of length squared (L^2). Similarly, because velocity is measured in metres per second, kilometres per hour and so on, it is said to have dimensions of length divided by time (L/T).

> **"Everyone with an IQ exceeding their shoe size knows these stories are twaddle dreamed up by PR outfits"**

This leads to what one could call the Law of Laws: every valid formula must be dimensionally homogenous, having the same dimensions all the way through. Take Einstein's famous formula relating energy and mass, $E=mc^2$. On the left, we have energy. This has dimensions of mass x length^2 divided by time^2, or $M(L/T)^2$. Checking Einstein's formula we find its right-hand side is mass x the speed of light^2, which also has dimensions of $M(L/T)^2$. So Einstein's formula passes the dimensions test.

In contrast, Galton's 'law' fails. It's a ragbag of volumes, temperatures and pure numbers that don't even have dimensions. Most of those silly 'formulas for the perfect X' also fail the test. But the Law of Laws has a more positive side, by giving insights into what's important in a physics problem even when we're not entirely sure what to include. Simply demanding that both sides of a formula have the same dimensions can reveal that some apparently crucial factor is actually irrelevant, while others are more important than we might think.

For example, using such 'dimensional analysis' to find a formula for how far a bullet will travel reveals that the bullet's mass is irrelevant while its launch velocity is very important: doubling it quadruples the bullet's range. Theorists routinely use dimensional analysis for help in everything from aerodynamics to the quest for the ultimate Theory of Everything. And a quick check of the dimensions of those PR formulas will reveal that they're usually based on the Theory of Nothing. ■

ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham

ILLUSTRATOR: DEM ILLUSTRATION

1 MINUTE EXPERT

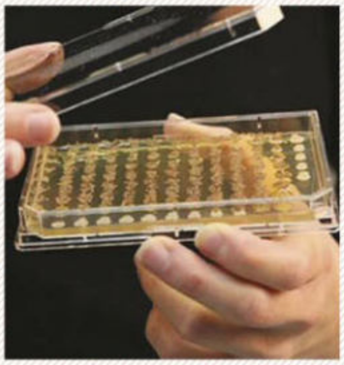
Bacterial fight clubs

Er... are you sure you're supposed to be talking about that?
Don't worry – it's nothing to do with Tyler Durden. It's a method of searching for new drugs that was created by chemists at Nashville's Vanderbilt University.

Tell me more.
The work is based around secondary metabolites – compounds released by bacteria to fight off organisms. Lots of antibiotics and anti-cancer compounds are either secondary metabolites or their derivatives.

So where does the fighting bit come in?
Analysis of microbial genomes suggests that each of the 150,000 distinct species of bacteria contain the blueprints for hundreds of secondary metabolites. The problem is, getting the bacteria to produce them can be tricky. By pitting microorganisms against one another in controlled 'fight clubs', the researchers were able to trigger the release of secondary metabolites.

Have they found any new drugs?
It's still early days but one new compound, dubbed circomicin, has a structure similar to current antibiotics and has already demonstrated tumour-killing qualities.


Bacteria go head-to-head in the laboratory

At the top is a prototype of the craft. Below it is what NASA hopes it will look like in the future

SPACE

NASA plans to fly a drone on Mars

MOVE OVER CURIOSITY, NASA's Armstrong Flight Research Center is testing a prototype drone that could become the first craft to fly through the Martian atmosphere.

The craft is dubbed the Preliminary Research Aerodynamic Design To Land On Mars, or Prandtl-m. While it doesn't seem like the catchiest acronym, the father of modern aerodynamics was the German engineer Ludwig Prandtl. We see what you did there, NASA...

The craft, which is based on a glider design created by NASA interns in 2013, could ride in a CubeSat as part of the Mars rover payload scheduled to leave for the Red Planet in 2022.

Later this year, researchers will be releasing a prototype from a high altitude balloon at a height of 30,000m, which will simulate the flight conditions of the Martian atmosphere. If successful, it will undergo further tests involving higher altitudes and CubeSat containers.

The drone will be made from fibreglass or carbon

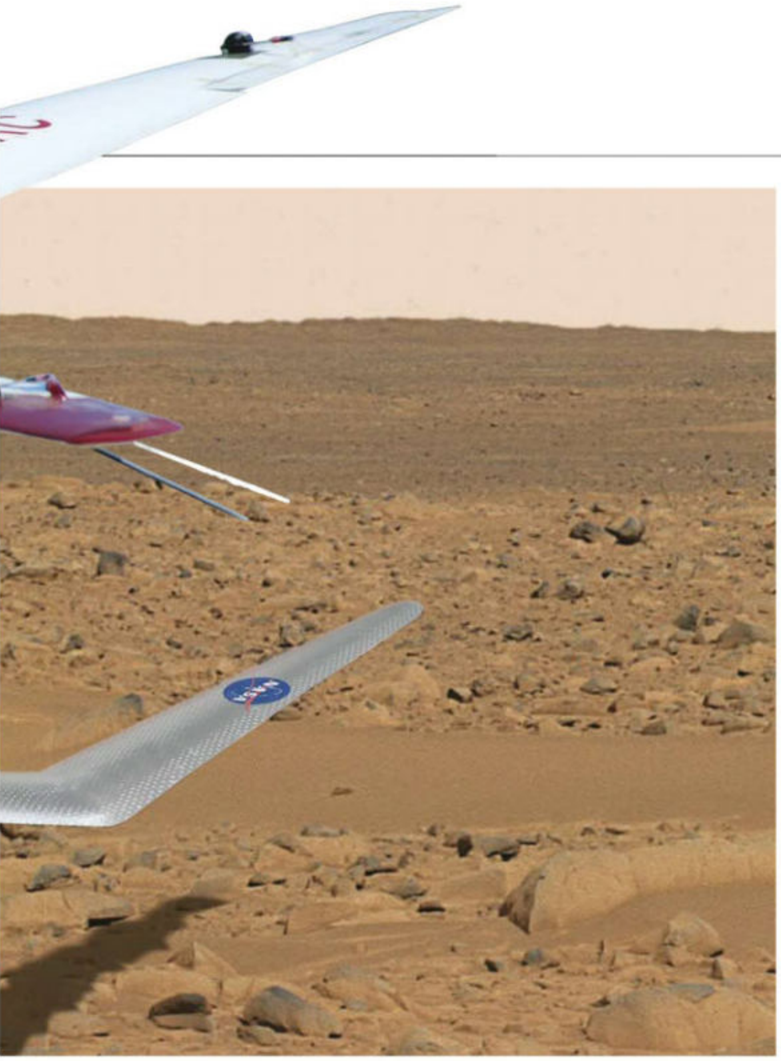
THEY DID WHAT?!

Researchers analyse the dreams of rats

What did they do?
A team at UCL placed rats on a straight track with a T-shaped junction blocked off by a transparent barrier ahead. They placed food at one end of the T and allowed the rats to view it. They then placed them in a sleep chamber for one hour before putting them back on the track with the barrier removed and allowing them to run into the T. The rats' brain activity was monitored at each stage of the experiment.

What happened?
Like humans, rats store 'mental maps' in the hippocampus, an area of the brain associated with memory and navigation. However, when resting, 'place cells' corresponding to the route they needed to take to the food became active in the animals' hippocampus suggesting they were

PHOTO: NASA X2, ICAROS, ISTOCK, ANNE RAYNER/VANDERBILT



fibre, it will have a wingspan of around 60cm and will weigh just over 1.2kg on Earth. On Mars, it will weigh roughly 500g, thanks to the Red Planet's lower gravity.

"It would be able to deploy and fly in the Martian atmosphere and glide down and land," explains Al Bowers, Chief Scientist at the Armstrong Flight Research Center. "The Prandtl-m could overfly some of the proposed landing sites for a future astronaut mission and send back to Earth very detailed high-resolution photographic map images that could tell scientists about the suitability of those landing sites. It would have a flight time of around 10 minutes. The aircraft would be gliding for the last 2,000 feet [609 metres] to the surface of Mars and have a range of about 20 miles [32 kilometres]," he adds.

Despite its boomerang shape, however, there's no chance of the Prandtl-m returning to Earth.

'dreaming' of scurrying towards the snacks.

What does that mean?

The findings indicate that the hippocampus is involved in planning routes and recording those that have already been witnessed. This may imply that the ability to imagine future events is not uniquely human, the researchers say.

Dreaming of the route that leads to tasty treats... awwww

PATENTLY OBVIOUS with James Lloyd

Inventions and discoveries that will change the world

The right trousers

IF YOU'VE EVER envied Iron Man's suit, here's one for you. Designed to help the elderly or injured walk, Samsung's robotic suit is an exoskeleton for the legs. Two electromyogram sensors detect electrical activity in the muscles, helping to determine the wearer's position in the walking cycle. Motors then spring into action, providing power to the legs. Let's hope it's portable enough to haul up mountains – we could do with some extra help when hiking.

Patent application number: US 20150134080

Ear ear

FORGET FINGERPRINTS: HOW about using your ear to unlock your phone? A system from Amazon uses the unique shape of a person's ear to identify them, unlocking the phone when they hold it to their lug. The technology will be able to determine which ear you're holding it to – adjusting the positions of buttons to suit your left or right hand – and even ramps up the speaker volume if it detects your ears are covered by hair or a hat. Handy if you're going to a party as Sherlock Holmes...

Patent number: US 9,049,983

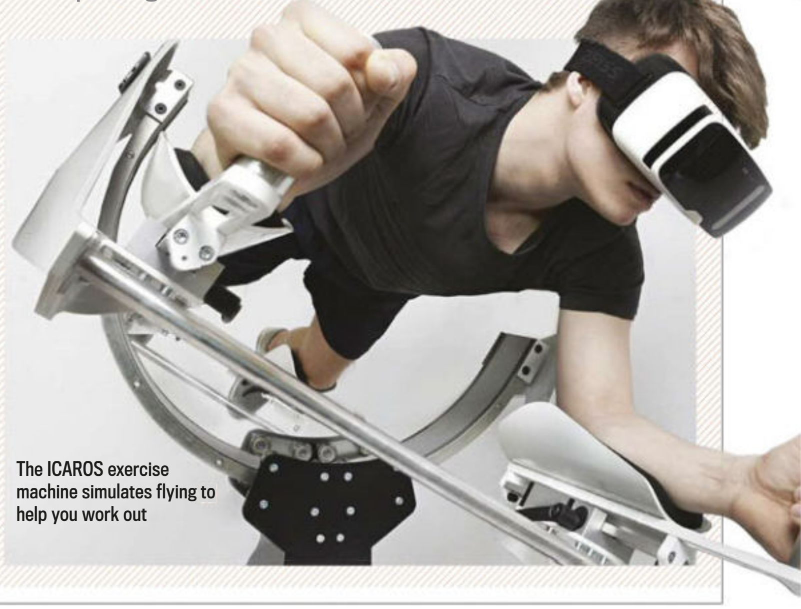
Flying fit

LET'S FACE IT, exercise can be a dull activity. Those endless miles running on the treadmill; those countless hours sweating in a muggy, overcrowded gym. Imagine if you could exercise while flying through outer space or soaring over a faraway land.

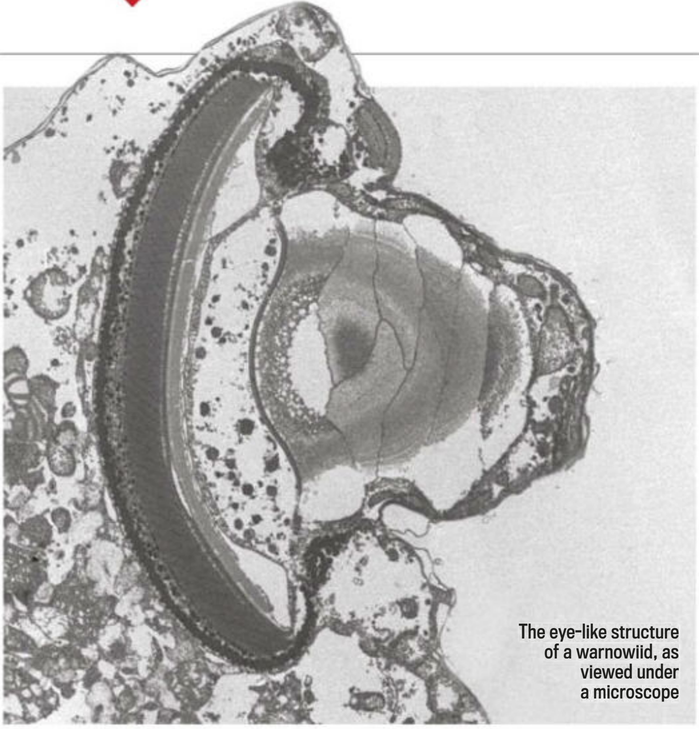
That's the experience offered by ICAROS, a combined fitness and gaming device developed by a team in Germany. The workout station is an unusually shaped cradle that pivots on two different axes. You position yourself on the machine by adopting a Superman pose, using the leg and arm rests to support your weight.

ICAROS then acts as your gaming controller. It allows you to steer your way through a flying simulator, which is beamed to you via a standard pair of VR goggles. In order to avoid crashing, you'll have to stretch and strain your body, giving you an all-over workout. You'll feel like Peter Pan, only a bit older and a lot more sweaty.

Patent pending



The ICAROS exercise machine simulates flying to help you work out



The eye-like structure of a warnowiid, as viewed under a microscope

ZOOLOGY

Plankton with human-like eye discovered

MEET THE WARNOWIID: a type of plankton that has been found to have a complex eye-like structure despite being made from just one single cell.

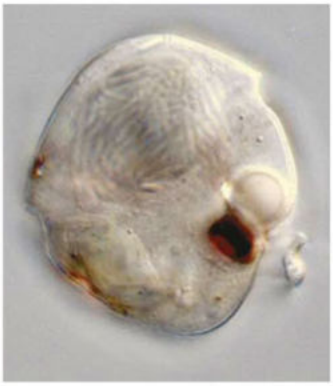
The predatory microbes were collected off the coasts of Japan and Canada by a team from the University of British Columbia. Once the researchers placed them under the microscope, they discovered that a dark purple spot situated within the organism was an ocelloid, a complex structure similar to a human eye.

"It's an amazingly complex structure for a single-celled organism to have evolved," says researcher Greg Gavelis. "It contains a collection of sub-cellular organelles that look very much like the lens, cornea, iris and retina of multicellular eyes found in humans and other larger animals."

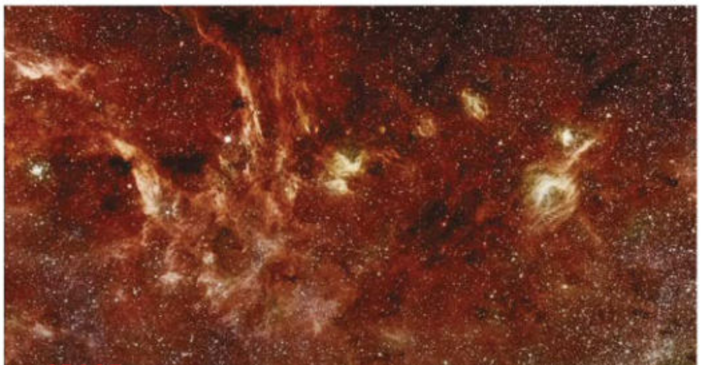
So far it's not entirely clear what warnowiids use the eyes for. The researchers suspect that they detect shifts in light as it passes though the transparent bodies of their prey. The structure could then send chemical messages to other parts of the cell, showing them in which direction to hunt.

The work neatly illustrates the idea of convergent evolution, a process by which very different organisms can evolve similar traits in response to their environments. Eye-like structures have evolved independently many times in different kinds of animals.

"When we see such similar structural complexity at fundamentally different levels of organisation in lineages that are very distantly related to each other, in this case warnowiids and animals, then you get a much deeper understanding of convergence," researcher Brian Leander says.



The dark red section is the 'retina', while the clear sphere is the 'cornea' and 'lens'



SPACE

Universe will ultimately tear itself apart

IT SEEMS THE Universe may not end with a bang or a whimper, but with a 'Big Rip'.

Researchers in the US have created a new theoretical model that suggests the Universe will eventually be expanding at such a rate that all matter will be violently ripped apart.

There's no need to start worrying though: it won't happen for another 22 billion years.

The model was proposed by Vanderbilt University mathematician Marcelo Disconzi and it rests on a property called bulk viscosity. This is a measure of how resistant a given fluid is to contraction or expansion. The fluid in question here is the Universe. Previously, researchers were unable to produce a model of the Universe that included this property without it breaking down and predicting certain situations in which the fluid was able to travel faster than the speed of light.

"This is disastrously wrong, since it is well-proven experimentally that nothing can travel faster than the speed of light," says Disconzi.

After confirming his model passed this test, Disconzi then teamed up with physicists Thomas Kephart and Robert Scherrer to see how it would fit into the broader cosmological picture.

In the 1990s, physicists discovered that the Universe is expanding at an ever-accelerating rate. Quite why this is occurring, however, is unclear. They theorised there must be an unseen repulsive energy spread throughout the Universe driving this process and named it dark energy.

There are currently a number of theories describing the ultimate fate of the Universe, with the most popular being the Big Freeze and the Big Crunch. In the former, the expansion continues indefinitely until it cools to the point of being incapable of hosting life. The latter states that gravity somehow overcomes the repulsive effect of dark matter and the Universe eventually contracts back together.

Disconzi's model, however, suggests another possibility: the Big Rip. Here, the expansion rate of the Universe becomes so great that all matter is pulled apart.

"In previous models with viscosity the Big Rip was not possible," says Scherrer. "But in this new model, viscosity actually drives the Universe toward this extreme end state."

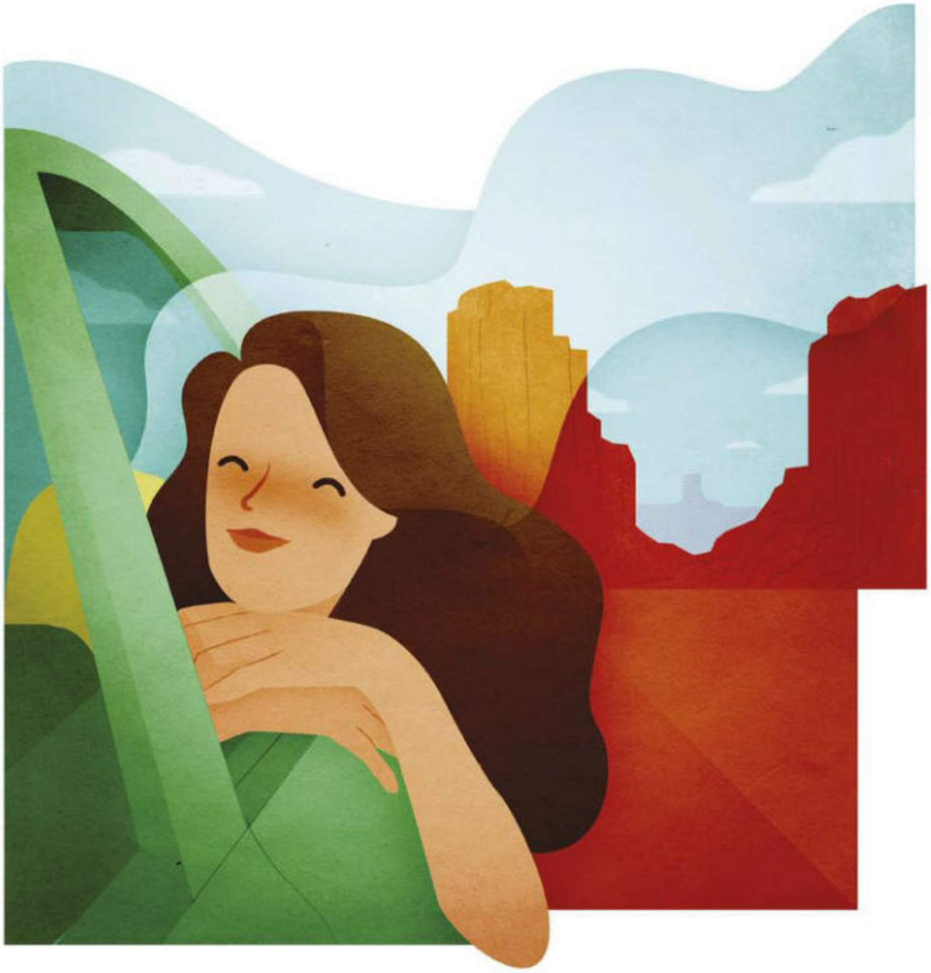
The team plans to test the model using supercomputers to crunch the complex equations and provide predictions that can be confirmed with experiment.

PHOTO: SCIENCE PHOTO LIBRARY, NASA/ESA

EVERYDAY SCIENCE

HELEN CZERSKI

How to make music while driving through a desert



WE WERE DRIVING through a stark and stunning landscape at dusk, still 80km (50 miles) from the location for the next day's documentary filming. The final orange glow of the sunset was picking out specific rocks so that they seemed to be on fire. Rob, our cameraman, could barely contain his excitement at the aesthetic smorgasboard whooshing past. Alex, the director, was at the wheel and worried about being late. He agreed that it was fabulous but said that we had no time to stop to film it. I laughed at Alex for being the strict schoolmaster, but the next rock was too much for Rob. He wound down his window a little way to take photos.

Immediately, a loud and low-pitched regular thumping filled the car. The whoomph-like noise was hammering on our ears and was pretty uncomfortable to listen to. Alex made a face, mustered his stoicism, and then after a few moments it occurred to him to open the driver's window just a tiny bit. The noise stopped. Rob happily snapped away, and then wound his window up. But I was excited and wanted to hear this strange sound again. Alex closed his eyes briefly, shook his head and braced himself. 'Whoomph, whoomph, whoomph…'

The reason that I was excited is that you don't often get to feel as though you're inside a musical instrument. I was imagining the air in the car being shunted about around me. When the first window was opened, the car turned into a rigid air-filled container with just one small opening to the outside. As the wind rushed past the window, it jostled the air molecules just inside, shoving on them and squashing the contained air slightly.

If you squeeze a balloon, it pushes back, and that's what was happening in the car. The squeezed air in the car started to push back out, slightly overshooting the window into the outside. And then the rushing wind on the outside pushed it back again. A regular pulsation was set up: air was pushed in and then it pushed back. We heard one 'whoomph' on each cycle. This effect is known as a 'Helmholtz resonance'. The air in a bigger container will pulsate at a slower rate, because it takes a long time to be squashed and to push back. In our car, there were between one and two pulsations each second.

> **"For a few moments we felt as though we were sitting in the guts of a musical instrument, one being played by the wind"**

When somebody blows across the top of a beer bottle, exactly the same thing happens. The note that you hear comes from the air inside the bottle pushing on the outside air, making a single note at the frequency of the air pulsating in and out of the bottle. But because the beer bottle is smaller, the pulsation happens much more quickly, perhaps a few hundred times each second. So instead of hearing all the individual thumping noises that there are on the inside, you just hear a single note at the frequency of the pulsations.

Back to the car. The trick Alex used to make the sound go away, opening a second window, spoils the setup. In this scenario the container now has two holes on opposite sides, so if you shove air into one, it's just pushed out of the other one. It's not squashed, so it can't push back, and there is no pulsation. While the noise in the car was a bit uncomfortable to listen to, it was worth it for a few moments to feel as though we were sitting in the guts of a musical instrument, one being played by the wind as the desert rushed by. ■

DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter whose most recent series was *Super Senses*

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INTO THE FUTURE

STEPHEN BAXTER

How stem cells, food, GMOs and pills could feed the world

JULY 2015 SEES the 30th anniversary of Live Aid, a brave response to a famine in Ethiopia. Its slogan was 'Feed The World': a laudable ambition, but one that seems further away than ever, with an increasing human population and the environmental impact of agriculture becoming more apparent.

Technological advances have helped feed the world before. From the 1940s to the 1960s, the 'Green Revolution' dramatically increased global food production thanks to high-yield grain varieties, new fertilisers and pesticides, and advances in farm management techniques. What of the future? The most familiar technological advance in food production today is probably the use of genetically modified organisms (GMOs) in which individual genes are lifted from one species and inserted into another. GM foods remain controversial; there is no scientific evidence that they offer any risk to people, but the evidence of their impact on biodiversity is more ambiguous. It is estimated that some 10 per cent of planted crops are already GM.

Other advances may come from unexpected directions. For 15 years the European Space Agency has been running a research project called MELISSA – the Micro-Ecological Life Support System Alternative – in which tightly controlled ecological loops are studied, with human waste going in one end, and rice, potatoes, soya and a protein-rich algae called spirulina being produced at the other. The purpose is to feed astronauts in space colonies and on missions, but the study of highly efficient food production systems may have wider applications.

Elsewhere, new varieties of plants are being developed that may be able to grow on currently unproductive land. At the Commonwealth Scientific and Cultural Research Organisation (CSIRO) based in Canberra, Australia, new varieties of wheat are being developed with longer roots, which may be able to grow in drought-prone areas where any available water lies deep underground. What of those meat-eaters who don't fancy a diet of lettuce and algae? 'Frankensteak' meat production systems are being trialled in which stem cells from a pig, for example, are used to 'grow' slabs of pork in vats, without the necessity, and inefficiency, of raising whole animals.

"'Frankensteak' meat production systems are being trialled in which stem cells are used to 'grow' slabs of meat"

Solutions still more radically divorced from traditional agriculture may make themselves available. *BBC Focus* 269 (July 2014) reported on Soylent, an experimental energy-efficient food source which would come as a powder to which you would add water and then drink. Meanwhile, the Pentagon's R&D department is trying to develop battlefield foods in which 2,000 calories might be crammed into a single capsule.

Food production seems to have been essential in human evolution. Once upon a time, our ancestors had small heads, large teeth and long guts. They were adapted to eating and digesting tough raw foods. It seems that because *Homo erectus* began to use fire to cook food and make it more digestible, they acquired smaller teeth and smaller guts. With their additional available energy, they developed larger brains.

In future, maybe technology will ultimately free us from a dependence on nature altogether. HG Wells, in an essay published in 1897, speculated that once artificial photosynthesis was achieved, technology would take over food production entirely, with no need for animals, plants or even algae: "In the last days man will be alone on the Earth, and his food will be won by the chemist from the dead rocks and the sunlight." ■

STEPHEN BAXTER is a science fiction writer who has written over 40 books. His latest is *Ultima*, published by Orion

ILLUSTRATOR: ANDY POTTS

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A MODERN BOMB...
Today's weapons are capable of wreaking even more destruction than Little Boy
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SCIENCE AND TECHNOLOGY

RISING FROM THE ASHES

Seventy years ago, Hiroshima was decimated by the Little Boy atomic bomb. **Mun Keat Looi** charts the city's unexpected recovery in the weeks and months following the blast

Listen to an *Inside Science* show about Hiroshima on 6 August **bit.ly/Inside_Science**

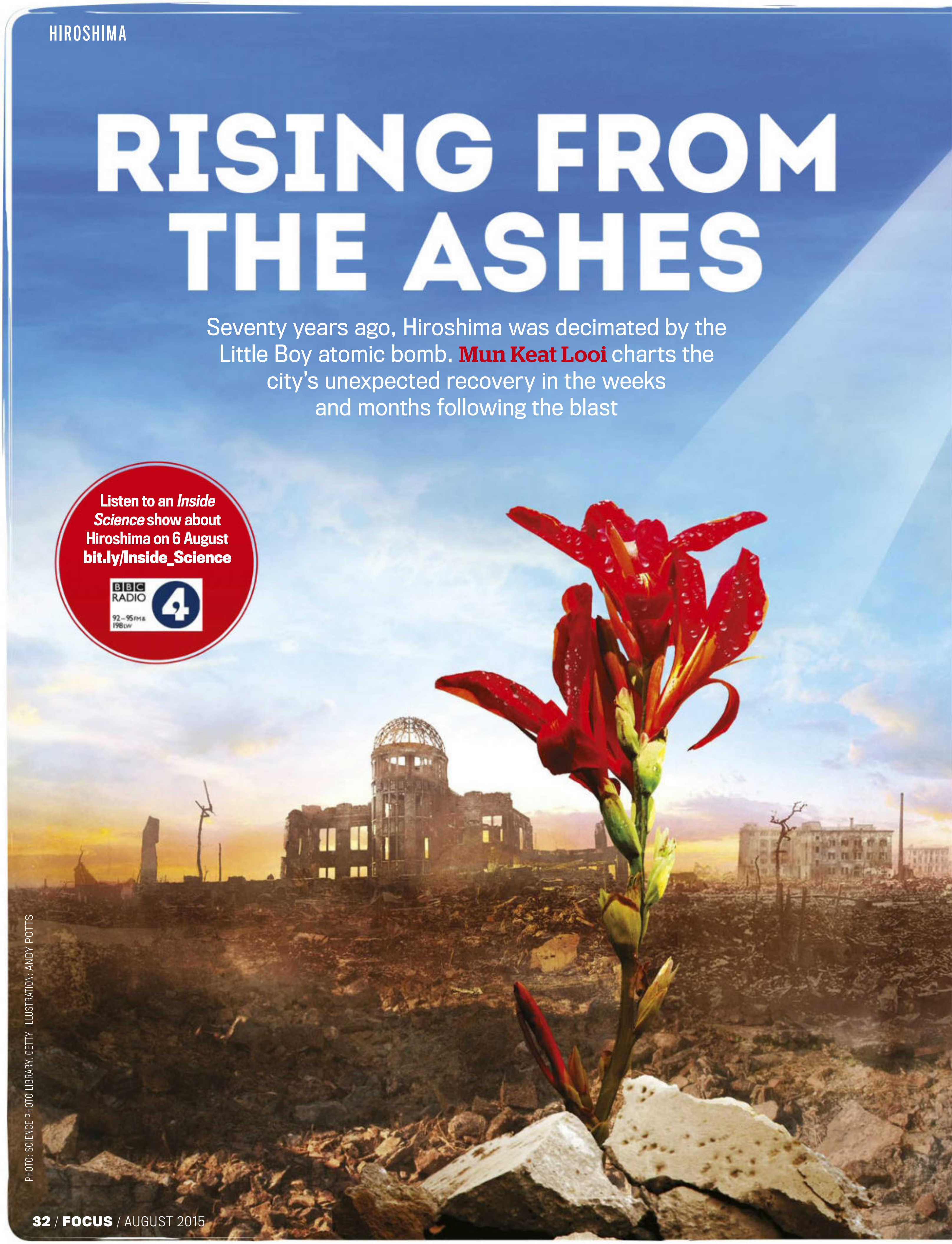


PHOTO: SCIENCE PHOTO LIBRARY, GETTY ILLUSTRATION: ANDY POTTS

> **“Looking up, the orange colour of the Sun, along with the sound of the plane overhead. As I covered my head a huge bang came and the entire barracks was blown away, many people losing consciousness as a result. From behind a windowsill, the hell that was the reality in front of me was being taken in by my eyes, accompanied with the groans of its victims”**
>
> **Hiroshima survivor**

HIROSHIMA, JAPAN, MONDAY 6 August 1945. At 8.15am, the US bomber Enola Gay dropped ‘Little Boy’, the first nuclear weapon ever used in warfare. Measuring just 300cm in length and 70cm in diameter, the atomic bomb was the pinnacle of the Allies’ $2m Manhattan Project. It was a marvel of scientific engineering, and an awesome show of military might delivering unprecedented destruction. Just three days later, Fat Man exploded over the city of Nagasaki. These remain the only two instances of nuclear bomb use in a warfare situation.

Little Boy detonated just 43 seconds after its release, and the 4,400kg payload unleashed a punch equivalent to 15 kilotonnes of TNT. Little Boy missed its target, which was the T-shaped Aioi Bridge traversing the city’s Ota and Motoyasu rivers, because the wind carried it around 250m away. There, it detonated 600m above ground, reportedly over a surgical clinic.

The explosive trigger set off the real mechanism. The bomb contained radioactive uranium-235, which was pushed into a spiral of decay. Each atom broke down to release neutrons, gamma rays and a huge amount of energy. These parts in turn destabilised neighbouring uranium atoms, in a nuclear fission chain reaction that used up 10 per cent of Little Boy’s 64kg of uranium stock.

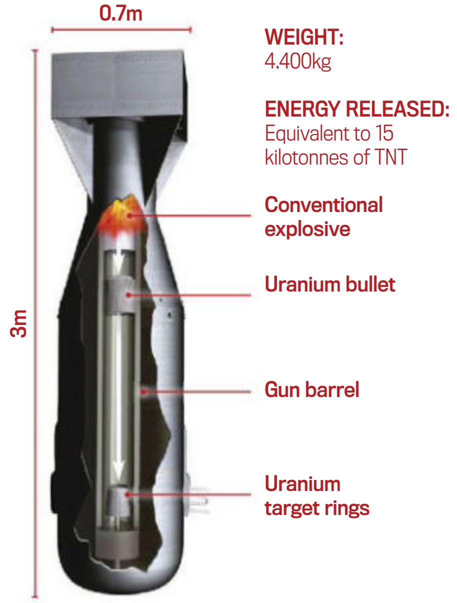
Within one second, a fireball 280m in diameter burst forth with a core temperature of over 1,000,000°C. Its heat rays raised surface temperatures to between 3,000°C and 4,000°C (iron melts at 1,500°C), scorching anything exposed to it. Birds burst into flames mid-flight. Paper as far as 2km away ignited. Entire houses were set alight, and structures collapsed in fires that would rage for another six or seven hours.

HEAT BLAST

The extreme temperature rise suddenly expanded the air around it, generating a tremendous blast travelling faster than sound. Just 500m from the centre of the blast, the atmospheric pressure reached 19 tonnes per square metre. Anyone not already incinerated was blasted by the splintered glass of exploding buildings – survivors alive today still have fragments embedded in their bodies. Then, a reverse. The sudden drop from high to low air pressure in the space behind the blast caused a tremendous backdraught, popping the eyeballs and internal organs of anyone unfortunate enough to be caught in it. Nearly everyone within a kilometre of the detonation centre (the ‘hypocentre’) died.

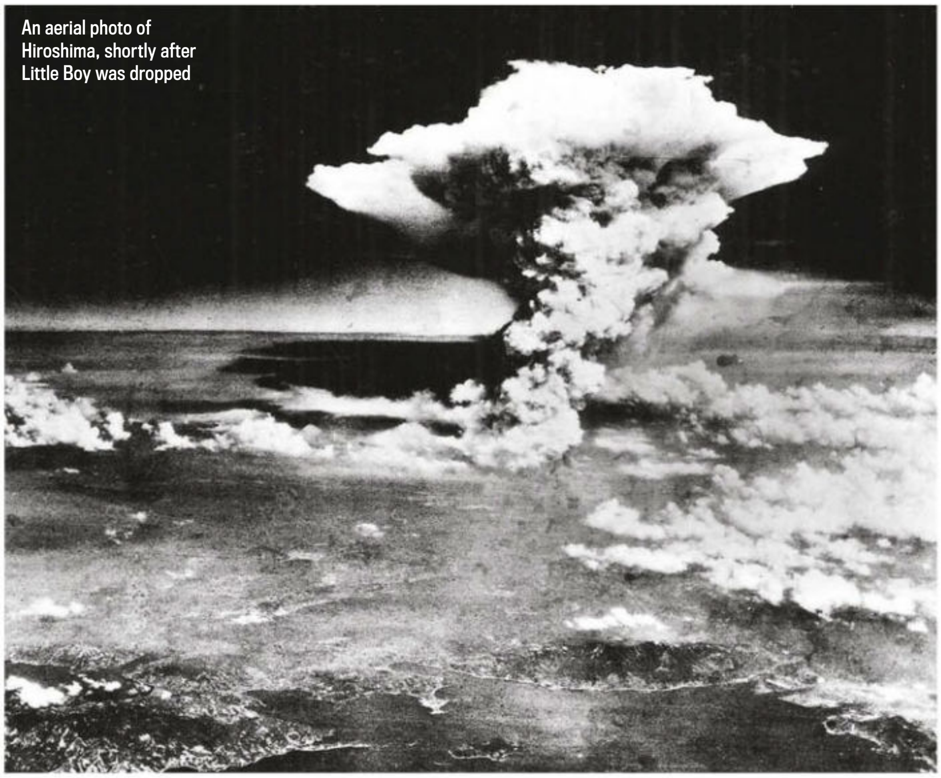
In fact, it could have been worse. Had Little Boy delivered its payload into the ground and not exploded in mid-air, its toll to the population and environment could arguably have been higher. As it was, it was still devastating. As the fireball rose, the ascending air currents surged into the stratosphere, carrying the

THE ATOMIC BOMB ‘LITTLE BOY’



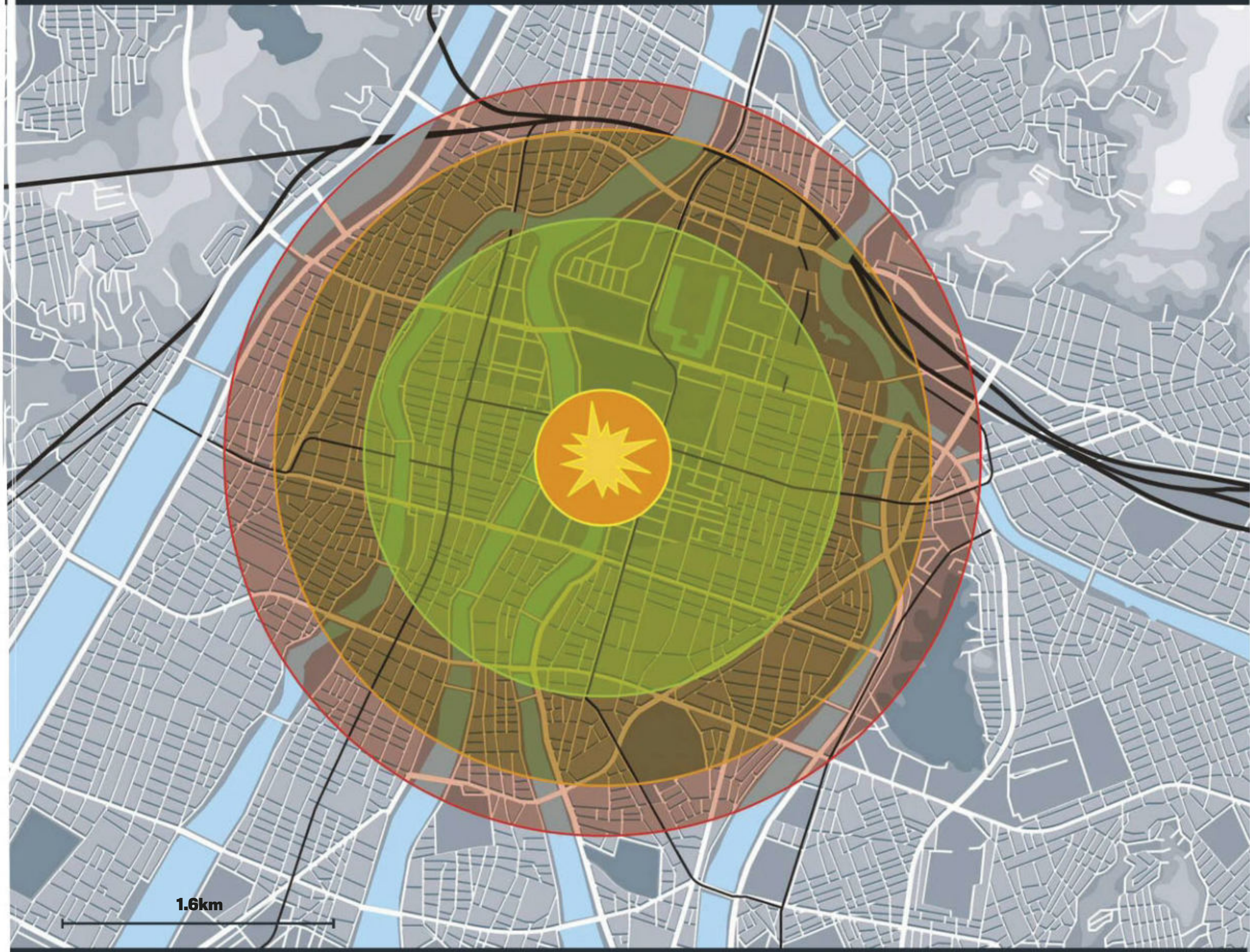
WEIGHT:
4.400kg

ENERGY RELEASED:
Equivalent to 15 kilotonnes of TNT


An aerial photo of Hiroshima, shortly after Little Boy was dropped

BLAST RADIUS OF HIROSHIMA

Effect of a 15 kilotonne atomic bomb



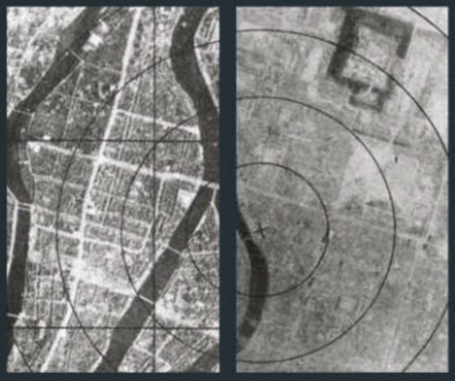
✸ **Fireball**
The Little Boy bomb was detonated 600m above the city. A fireball measuring 280m in diameter exploded forth, raising surface temperatures up to 4,000°C

🟧 **All buildings collapse**
Even heavily built concrete buildings are severely damaged or demolished; fatalities approach 100 per cent.

🟩 **High levels of radiation**
Those closest to the bomb received the highest doses of radiation.

🟫 **Residential buildings collapse**
The atom bomb destroyed 76,000 houses, many of which were built from wood. Around 90 per cent of the city's buildings were within 3km of the impact zone.

🟥 **Thermal radiation**
Around 50 to 60 per cent of people within 2km of the hypocentre suffered from excessive scar tissue because of burns to the skin. While burns were worse in the victims that were closest to the bomb, even 2km away the temperature was still sufficient to cause paper to ignite.



Hiroshima before and after bomb, aerial view

PHOTO: GETTY ILLUSTRATOR: PAUL WESTON

Hiroshima as it happened

Bomb dropped
At 8.15am, Enola Gay drops Little Boy on Hiroshima. A total of 10 per cent of its 64kg of uranium-235 undergoes nuclear fission.

6 August 1945

Fireball
The Little Boy nuclear bomb emits a 280m fireball across the city, increasing the surface temperatures up to a scorching 4,000°C.

1 second later

Expansion
The sudden rise in temperature expands the air. Atmospheric pressure reaches 19 tonnes per square metre. Almost every structure collapses.

Pressure plunge
Air pressure near the hypocentre plummets from high to low. This causes air blowing out from the hypocentre to reverse, sweeping winds towards the centre with tremendous force.

Poison rain
Black rain falls, showering the west of the city in dark droplets of mud, dust, soot and radiation from the mushroom cloud.

30 minutes later

remaining 90 per cent of Little Boy's radioactive material – which hadn't undergone nuclear fission – with it. Those who came near the hypocentre for rescue and relief or to search for their families absorbed radiation and fell ill.

Much of the radiation took the form of gamma rays, but the major damage came from the 10 per cent that was made up of neutrons. These had the potential to cause more damage to body cells.

Half an hour after the explosion, black rain fell. The iconic mushroom-shaped cloud of the explosion drifted northwest, showering western Hiroshima in dark droplets of mud, dust, soot and radiation. Dead fish floated to the surface in ponds and rivers where the rain fell. Yet the survivors, burnt, parched and desperate, drank the rain.

ATOMIC AFTERMATH

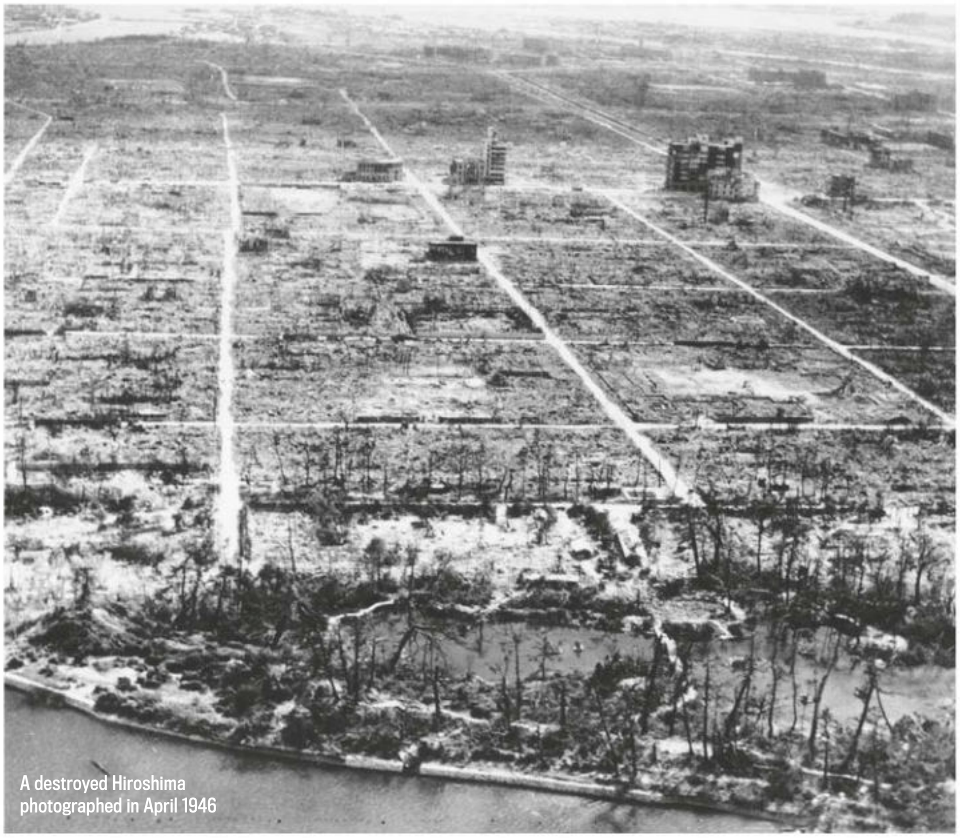
People started vomiting several hours later. After a few days, the first symptoms of radiation sickness were evident: fever, fatigue, bleeding in the gums and under the skin. It was all cell damage caused by radiation. Hair thinned and eventually just broke off. Diarrhoea, which for some lasted as long as three months, came from damaged cells lining the intestines. Those on the receiving end of the highest doses died within 10 to 20 days. The radiation also killed stem cells in the bone marrow so people couldn't make blood platelets, white blood cells or other key parts of the immune system. They bled out and couldn't fight infections. Many died within two months.

The closer a person had been to the hypocentre, the higher the radiation dose they'd received. The average dose for people within 2.4km of the bomb was 200mSv (millisieverts) – 100 times the level most people are exposed to in a year. Those closest to the bomb received 500mSv or more. Deaths from radiation sickness continued to rise for the next month, and didn't decline for another month after that – though it was hard to tell whether a death was from radiation, injuries or burns.

> **"About three seconds after a blinding flash of light, a thunderous roar came down from the other side of the mountain. A big mushroom cloud could be seen growing, glinting brilliant silver under the Sun"**
>
> **Hiroshima survivor**

The survivors of Hiroshima were scarred mentally and physically. Around 50 to 60 per cent of those within 2km of the hypocentre suffered excessive scar tissue. Cataracts were common. Studies have found "statistically significant excess risks" in survivors for chronic hepatitis, liver damage, thyroid disease and cardiovascular disease. For those in the womb when the bomb hit, the effect on mental disability rose with increased radiation dose, along with impaired growth and development. If the physical pain didn't hurt survivors enough, they also suffered stigma. They were shunned and sometimes persecuted by their peers, who were fearful of their possible disease and radioactivity.

There was more to come. "For those who survived the immediate effects of the atomic bombs, the most important long-term effect is an



A destroyed Hiroshima photographed in April 1946

Illness
The first symptoms of radiation sickness appear, such as fever, fatigue, bleeding in the gums, hair loss and diarrhoea.
6-8 August 1945

Switch on
Power in some areas of the city is restored. A limited rail service resumes on 8 August.
7 August 1945

WWII ends
Fat Man, the second atomic bomb, is dropped on Nagasaki, ending WWII.
9 August 1945

Hope blooms
Canna flowers miraculously emerge in the Hiroshima rubble, giving residents hope.
September 1945

Fresh start
Typhoons hit the Hiroshima region, bringing in new soil and sand.
October 1945

Nature wins
Hiroshima's cherry trees bloom once again, less than one year after the bomb hit the city.
Spring 1946

> "With their skin turned red, everyone seemed to walk like ghosts, with both hands reached out in front of them. Their skin, like the skin of potatoes, would stop at their nails and start to dangle from there"
>
> **Hiroshima survivor**

increased risk of cancer in those who were exposed to ionising radiation," says Prof Sarah Darby at the University of Oxford. Initial suspicions were that the radiation would cause genetic damage to sperm and eggs. But there has been no evidence of abnormal effects in children conceived by survivors after the bombing.

The survivors were not so lucky. An increase in cancer diagnoses was first noted in 1956 and grew throughout the 1960s. By 2000, around 1,900 survivors were thought to have died from cancer linked to radiation. Thyroid and breast cancers were the most common, along with stomach and lung. Arguably the worst was leukaemia. The signs of this blood cancer began appearing in children two to three years after the bomb.

Studies conducted by the Hiroshima-based Radiation Effects Research Foundation (RERF) have concluded that between 1950 and 2000, 46 per cent of leukaemia and 11 per cent of other cancer deaths among survivors were due to radiation from the bombs. "These studies confirm, beyond any reasonable doubt, that an increased risk of cancer can occur without causing [obvious] tissue damage," says Darby.

"The effect of radioactive black rain was definite and far-reaching," says

A mother and her child sit in the rubble of Hiroshima in December 1945

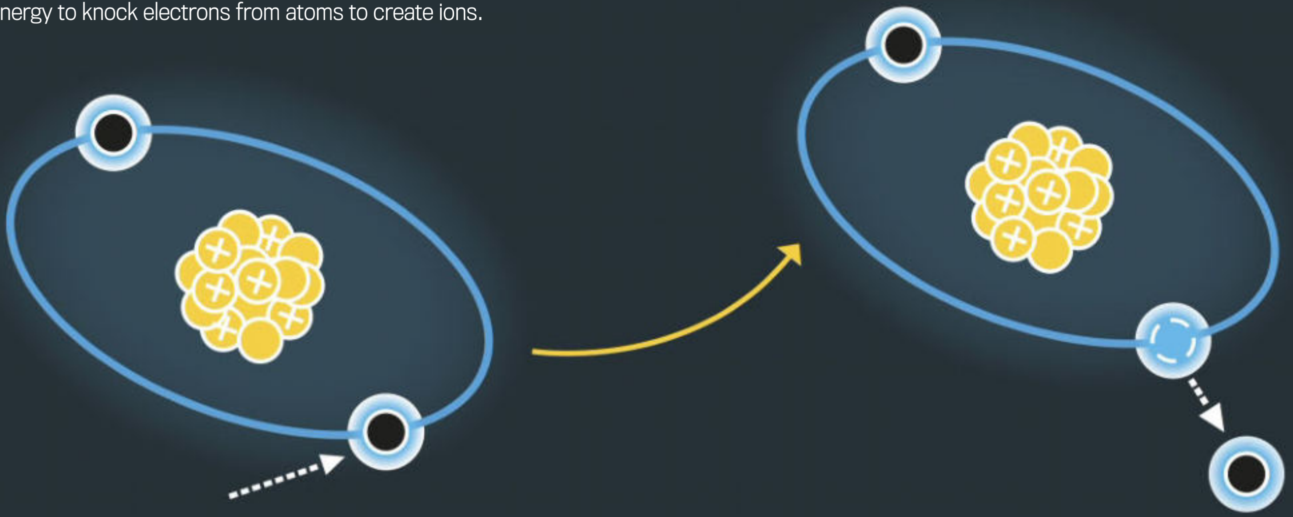
Scars on a Hiroshima survivor

PHOTO: GETTY, PRESS ASSOCIATION

RADIATION AND DNA How the bomb affected its victims' genes

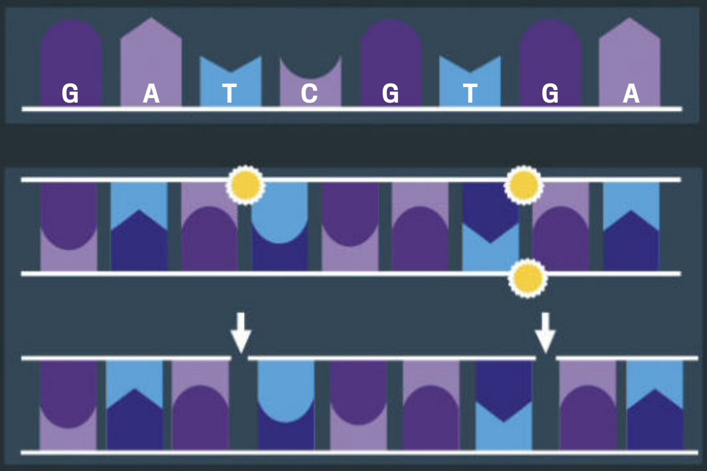
1. Radiation waves

Gamma and neutron waves, like those emitted in the explosion of Little Boy, are types of 'ionising radiation'. This means that they have enough energy to knock electrons from atoms to create ions.



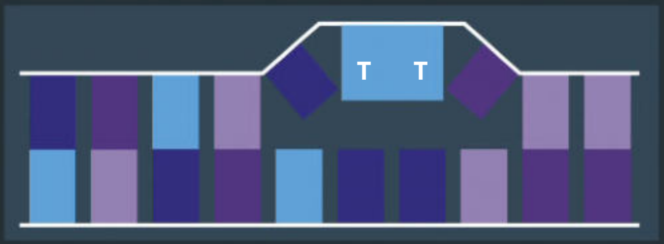
2. DNA damage

DNA contains four bases – cytosine, guanine, thymine and adenine. The ionised particles can cause breaks in the structure of DNA. Cells can repair some of these breaks, but they risk making mistakes during the repair. Breaks can occur across one or both strands. Cells find it much harder to fix breaks across double strands.



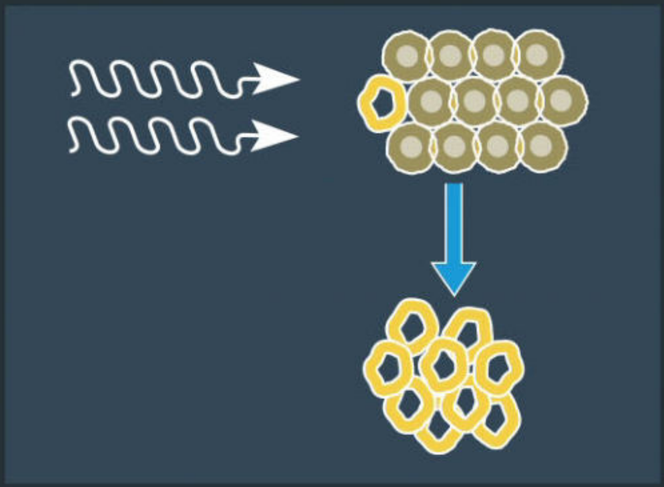
3. Code breaker

It is also possible for radiation to alter the genetic code directly. Gamma and neutron radiation can change one of DNA's bases into another, or can even make two bases stick together.



4. Cancer creator

The mistakes made by the broken DNA are called mutations. Sometimes, the mutations can be so bad that a cell no longer understands its instructions. Rather than repairing itself or self-destructing, it may multiply, which can lead to a tumour.

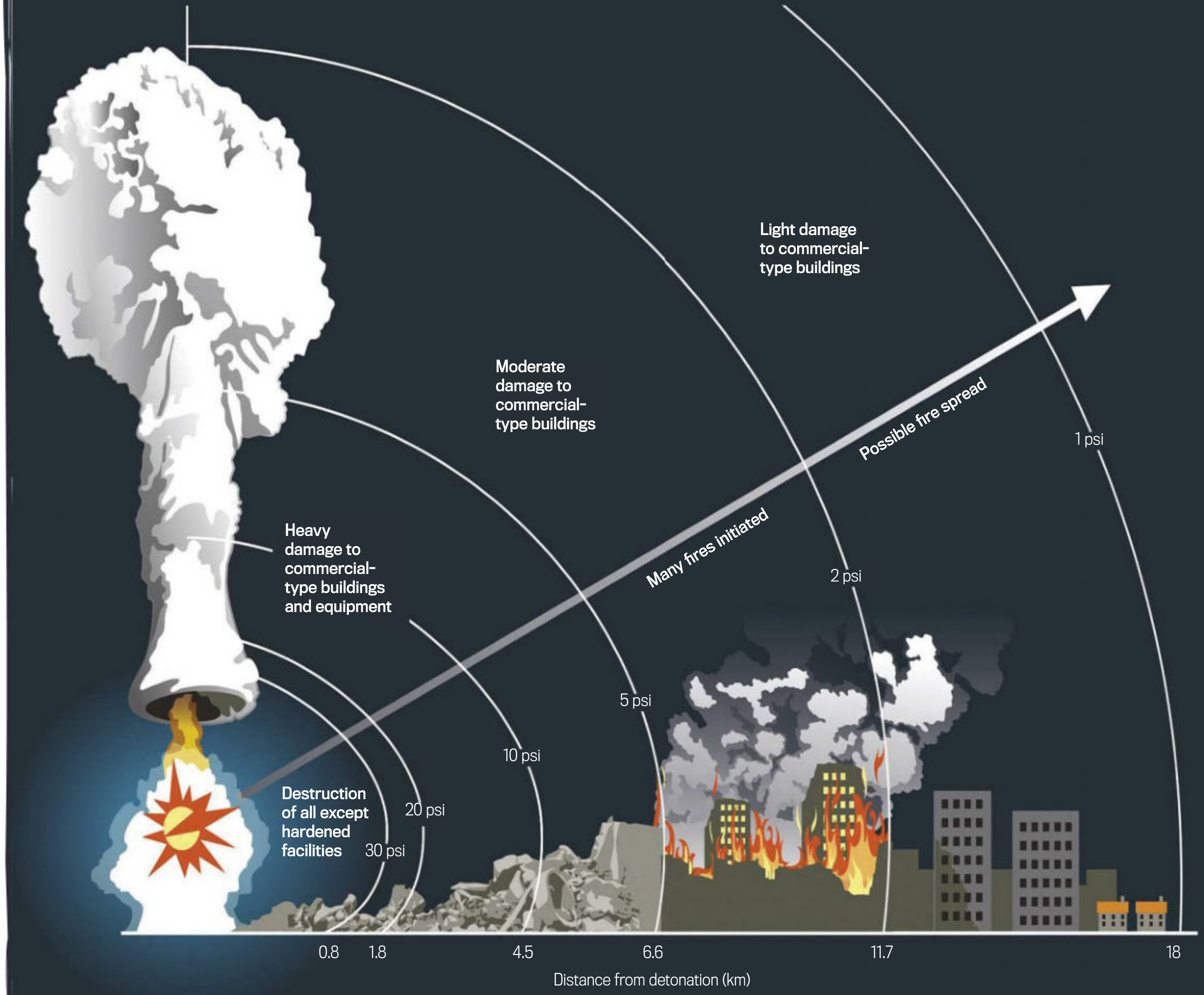


A MODERN BOMB...

Today's weapons are capable of wreaking even more destruction than Little Boy

THE BOMB DROPPED over Hiroshima unleashed a punch equivalent to 15 kilotonnes of TNT. This was sufficient to destroy the city and claim thousands of lives. Today, technology has moved on and more destructive weapons have been developed. The most powerful nuclear weapon ever detonated was the Tsar Bomba, with a yield equivalent to 50 megatonnes of TNT. It was tested over the Arctic Sea in October 1961. While many nuclear weapons have now been dismantled, a number of countries still possess them, including the USA, France, the UK, Russia, North Korea, Pakistan, Israel, China and India. Precise numbers of nukes are top secret. Below is a scenario in which a one megatonne bomb – up to 75 times the yield of Little Boy and roughly equivalent to the USA's B83 weapon – is detonated at a height of 2.2km.

One of the Royal Navy's Trident-class nuclear submarines



Light damage to commercial-type buildings
Moderate damage to commercial-type buildings
Heavy damage to commercial-type buildings and equipment
Destruction of all except hardened facilities
Possible fire spread
Many fires initiated
1 psi
2 psi
5 psi
10 psi
20 psi
30 psi
0.8
1.8
4.5
6.6
11.7
18
Distance from detonation (km)

After effects
The US establishes the Atomic Bomb Casualty Commission to study effects of radiation on survivors.
1947

Cancer cases
Some children who were exposed to radiation from the bombs start developing signs of leukaemia.
1947-48

Peaceful city
Hiroshima is designated a City for Peace by mayor Shinzo Hamai. This is a key event in the city's recovery.
1949

US exit
Japan becomes independent after US forces leave the country.
1952

Health scare
An increase in cancer diagnoses among survivors is noted, growing in number throughout the 1960s.
1956

Time bomb
Around 1,900 survivors are estimated to have died from cancer caused by the bomb.
2000

> **"Tests have shown that the radiation in an area exposed to the force of an atomic bomb will not be dissipated for approximately 70 years. Hiroshima will be a devastated area, not unlike our conception of the Moon, for nearly three-quarters of a century"**
>
> **Dr Harold Jacobsen**

Dr Aya Homei, a science historian at the University of Manchester. "The question of how far black rain reached has been a point of political contention in Japan, given that the answer to this has affected whether or not a survivor would be entitled to a government subsidy for their healthcare or not."

RECOVERY

Two days after the bombing, Manhattan Project physician Dr Harold Jacobsen was quoted saying that nothing would grow in Hiroshima for 70 years. The earth was scorched and melted. Around 90 per cent of the city's buildings had been within 3km of the impact zone. The explosion wiped out 76,000 houses, along with some 80,000 people. Any flora or fauna in the area were incinerated.

Around a month after the bombing, just 800m from the centre of the explosion, red canna flowers sprouted in rubble of Hiroshima's wasteland. This seemingly miraculous event gave hope and courage to the survivors. Yet this isn't actually that surprising, says Prof Jim Smith at the University of Portsmouth.

It would take "an awful lot" of radioactivity to stop plants from growing, he says. In fact, it would require hundreds of times more than the levels at Hiroshima, which were relatively low when compared to a nuclear accident like the Chernobyl power plant, where flora and fauna have similarly recovered. "It would surprise me if there was a problem with any plant recolonising," he says. "The impact of the actual bomb itself would be much more environmentally damaging than the subsequent radiation."

Canna flowers sprouted just one month after the bomb

On the night of 17 September 1945, the Makurazaki typhoon hit Hiroshima. It killed over 2,000 people and flooded large areas of the city. This natural disaster brought in new, radiation-free topsoil and sand from outside the region.

By spring 1946, Hiroshima's cherry trees were revived. By the summer, oleander flowers – known for their resilience and now the official flower of Hiroshima – were in bloom. As the city revived through further years of slow rebuilding, fruit and vegetables such as tomatoes and cucumbers were grown among the shacks multiplying in the city's midst. Crucially, 81 of the city's bridges survived, aiding recovery efforts. By the mid-1950s, Hiroshima's population had returned to its pre-war level.

Seven decades after the atomic bomb, Hiroshima is green once again. Many of its trees are gifts from donors from across Japan and overseas. Yet 170 trees are themselves survivors of the blast. These are known as 'hibaku jumoku' and consist of 32 different species. Just 370m from the blast centre stands a defiant weeping willow. Just like Hiroshima's human victims, the 'hibakusha', they live on. ■

MUN KEAT LOOI is an award-winning science writer and editor

Today, Hiroshima is a thriving industrial city with a population of 1.1 million

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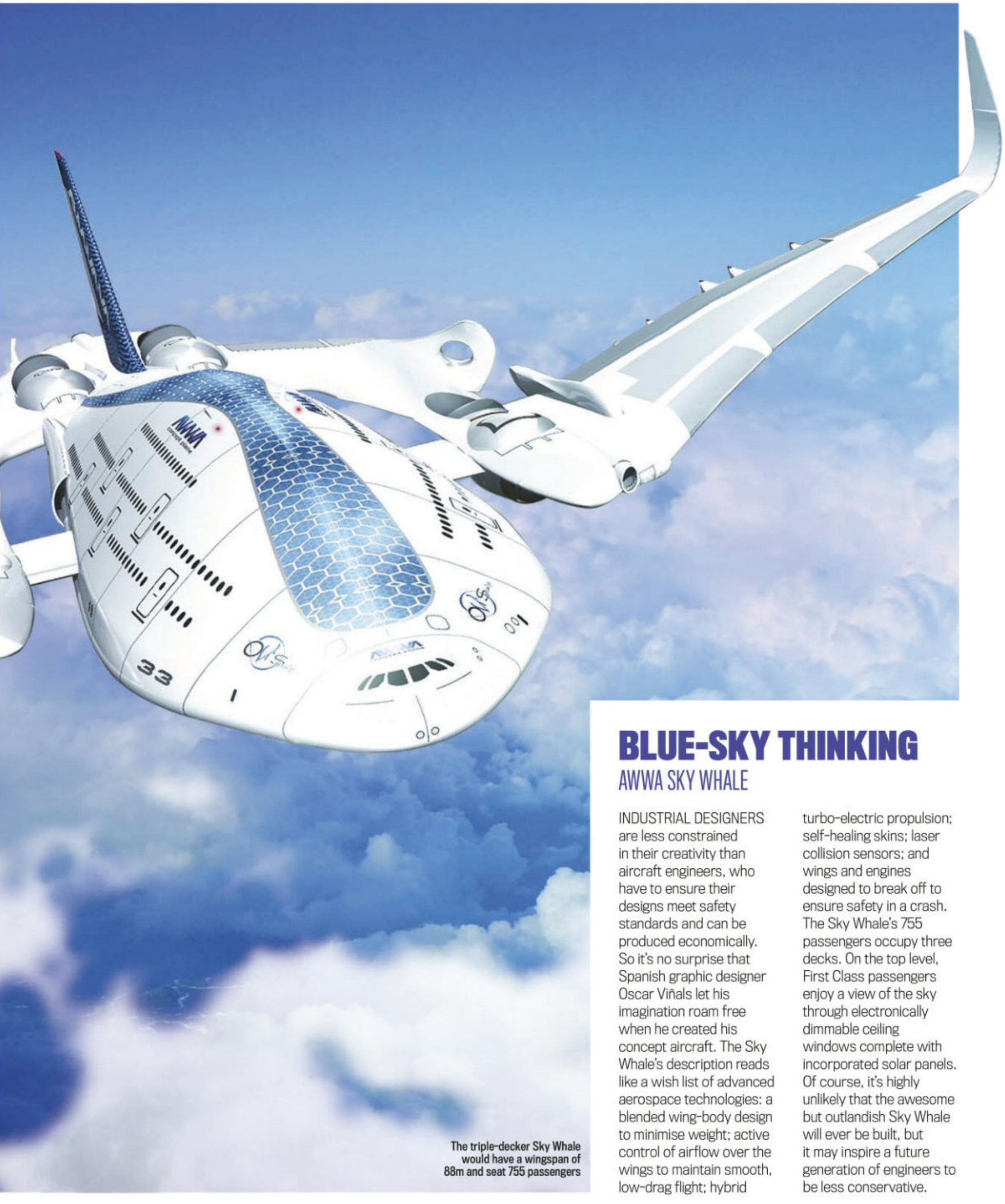
FLY ME TO THE FUTURE

Are you dreading sitting on a cramped plane for hours this summer? **Graham Warwick** looks at the concept aircraft that could transform commercial flights

PHOTO: OSCAR VINALS



The triple-decker Sky Whale would have a wingspan of 88m and seat 755 passengers

BLUE-SKY THINKING

AWWA SKY WHALE

INDUSTRIAL DESIGNERS are less constrained in their creativity than aircraft engineers, who have to ensure their designs meet safety standards and can be produced economically. So it's no surprise that Spanish graphic designer Oscar Viñals let his imagination roam free when he created his concept aircraft. The Sky Whale's description reads like a wish list of advanced aerospace technologies: a blended wing-body design to minimise weight; active control of airflow over the wings to maintain smooth, low-drag flight; hybrid turbo-electric propulsion; self-healing skins; laser collision sensors; and wings and engines designed to break off to ensure safety in a crash. The Sky Whale's 755 passengers occupy three decks. On the top level, First Class passengers enjoy a view of the sky through electronically dimmable ceiling windows complete with incorporated solar panels. Of course, it's highly unlikely that the awesome but outlandish Sky Whale will ever be built, but it may inspire a future generation of engineers to be less conservative.

The sleek shape of N+2 will help reduce air disturbances as the plane tears through the sky

ILLUSTRATION: NASA/LOCKHEED MARTIN, TECHNICON, IMPERIAL COLLEGE LONDON

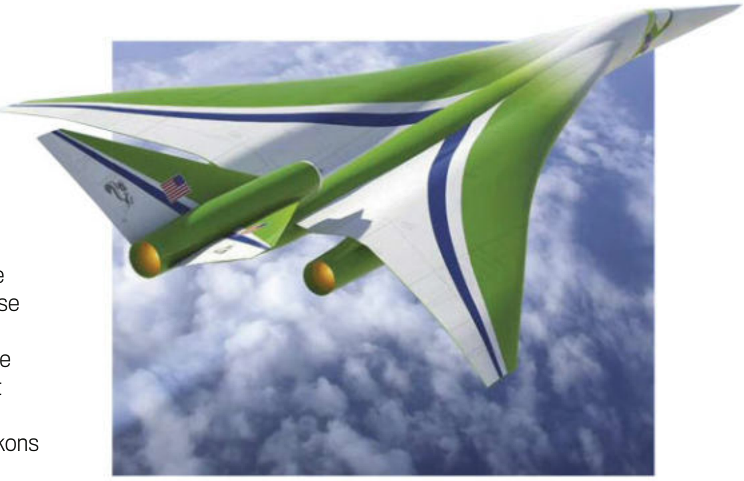
SILENT SUPERSONIC

LOCKHEED MARTIN N+2

IF A SUCCESSOR to Concorde ever emerges, chances are that it will look somewhat different from the iconic supersonic airliner. When an aeroplane breaks the sound barrier, air disturbances start to pile up into shockwaves at the nose, wing edges and tail. When these shockwaves combine, they are released in the distinctive sound known as a sonic boom. While the sound is impressive, it can startle wildlife, damage buildings and disturb residents who live near the flight path.

But Boeing, Lockheed Martin and NASA have now perfected tools to create an aircraft with a boom that has been reduced from the painfully loud double bang of Concorde to a barely perceptible whoosh. The secret lies in carefully controlling how the shockwaves form on the aircraft. The complex curves of the N+2's fuselage, the sharp sweep of its wing and the placing of its engines are all designed to control shockwave formation and minimise sonic boom.

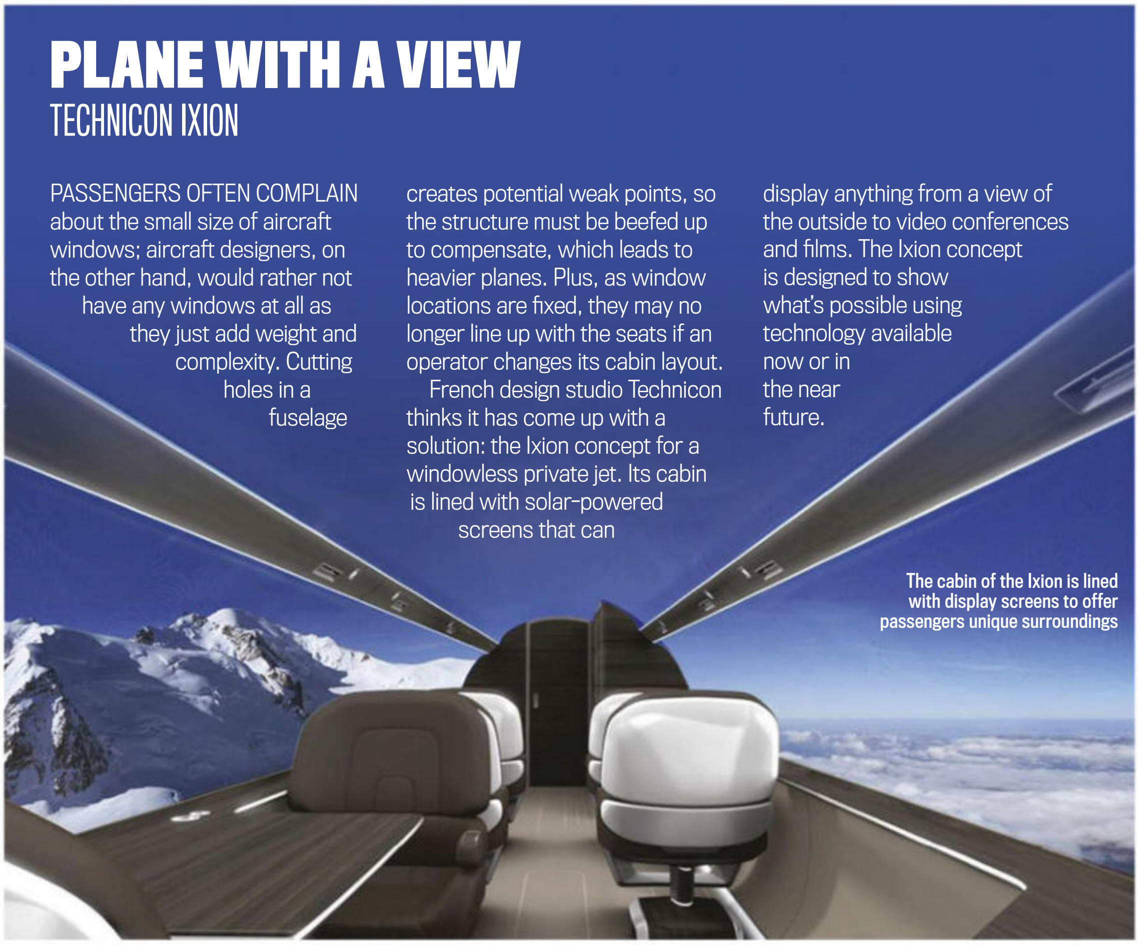
The sleek aeroplane would be able to seat 80 passengers, and Lockheed Martin reckons that the technology should be ready by 2025.



The Lockheed Martin N+2: supersonic travel without the boom

PLANE WITH A VIEW

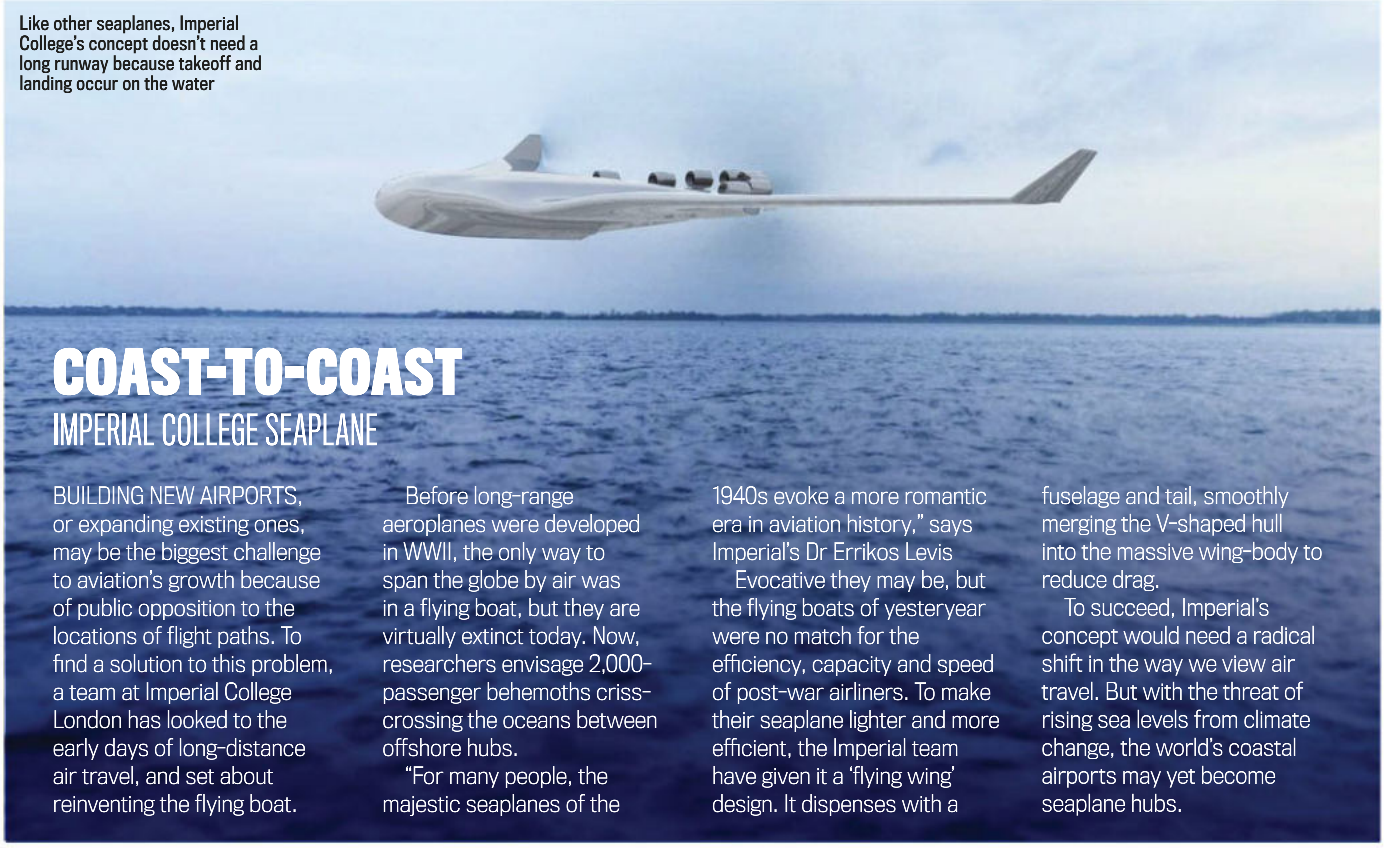
TECHNICON IXION



PASSENGERS OFTEN COMPLAIN about the small size of aircraft windows; aircraft designers, on the other hand, would rather not have any windows at all as they just add weight and complexity. Cutting holes in a fuselage creates potential weak points, so the structure must be beefed up to compensate, which leads to heavier planes. Plus, as window locations are fixed, they may no longer line up with the seats if an operator changes its cabin layout.

French design studio Technicon thinks it has come up with a solution: the Ixion concept for a windowless private jet. Its cabin is lined with solar-powered screens that can display anything from a view of the outside to video conferences and films. The Ixion concept is designed to show what's possible using technology available now or in the near future.

The cabin of the Ixion is lined with display screens to offer passengers unique surroundings



Like other seaplanes, Imperial College's concept doesn't need a long runway because takeoff and landing occur on the water

COAST-TO-COAST

IMPERIAL COLLEGE SEAPLANE

BUILDING NEW AIRPORTS, or expanding existing ones, may be the biggest challenge to aviation's growth because of public opposition to the locations of flight paths. To find a solution to this problem, a team at Imperial College London has looked to the early days of long-distance air travel, and set about reinventing the flying boat.

Before long-range aeroplanes were developed in WWII, the only way to span the globe by air was in a flying boat, but they are virtually extinct today. Now, researchers envisage 2,000-passenger behemoths criss-crossing the oceans between offshore hubs.

"For many people, the majestic seaplanes of the 1940s evoke a more romantic era in aviation history," says Imperial's Dr Errikos Levis

Evocative they may be, but the flying boats of yesteryear were no match for the efficiency, capacity and speed of post-war airliners. To make their seaplane lighter and more efficient, the Imperial team have given it a 'flying wing' design. It dispenses with a fuselage and tail, smoothly merging the V-shaped hull into the massive wing-body to reduce drag.

To succeed, Imperial's concept would need a radical shift in the way we view air travel. But with the threat of rising sea levels from climate change, the world's coastal airports may yet become seaplane hubs.

ILLUSTRATION: NASA, AIRBUS X2

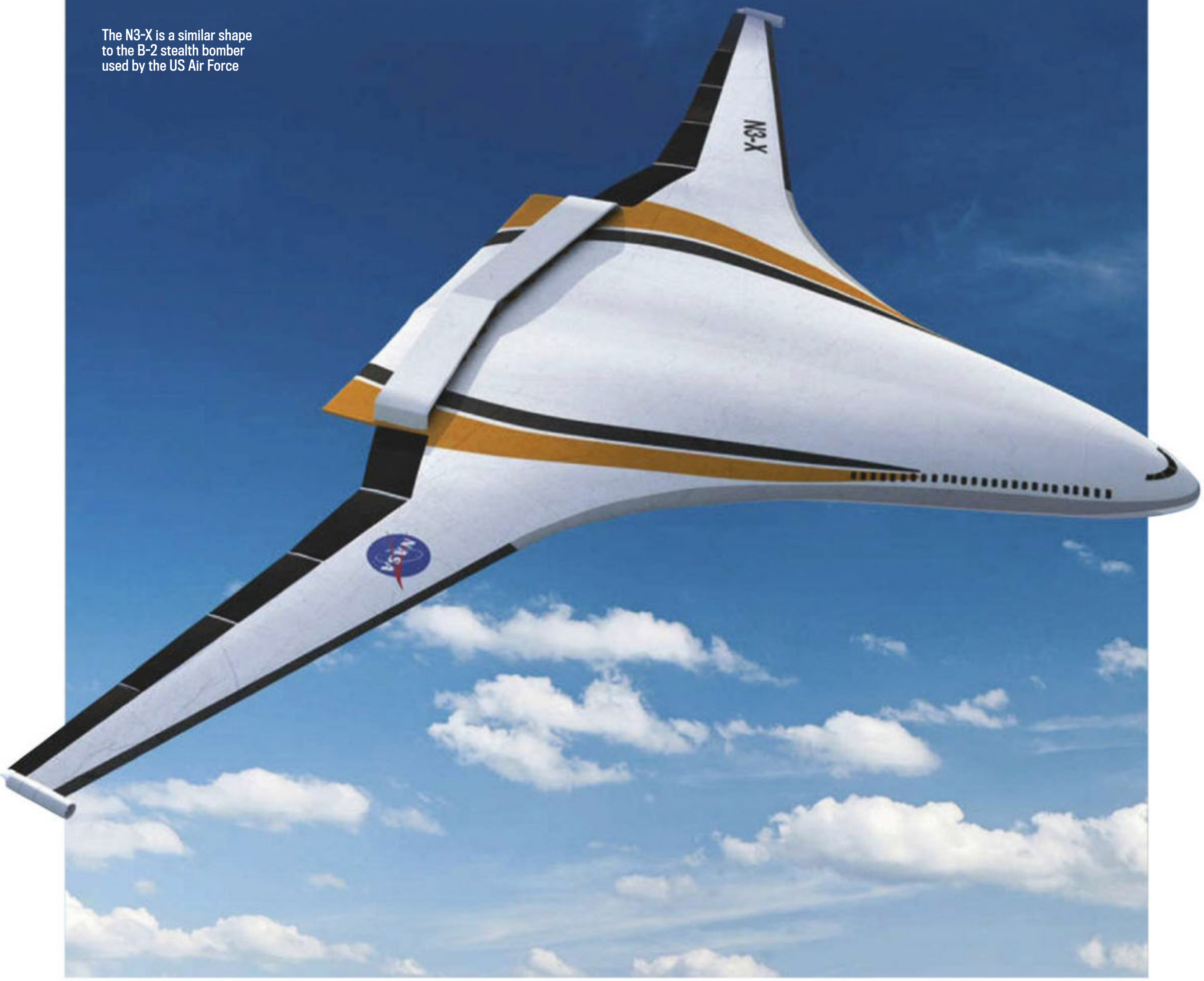
HYBRID HOPE

NASA N3-X

TOYOTA'S PRIUS HAS already proved that hybrid electric power is viable for motoring. But now a similar shift is beginning in aviation, as the industry strives to reduce its greenhouse gas emissions and cut its growing contribution to climate change. Perhaps the ultimate expression of this is NASA's N3-X, an aircraft that embodies many features that researchers are pursuing for future airliners.

Instead of turning jet fuel into thrust via two huge turbofans under the wing as in today's Boeing 777, the N3-X changes biofuel into electricity which it uses to drive a row of smaller fans positioned at the back. The 'flying wing' design is aerodynamically and structurally more efficient than today's 'tube and wing' aircraft, reducing fuel consumption, while the 'letterbox' inlet across its back cleans up airflow over the wide wing-body to minimise drag.

To become a reality, the N3-X will require there to be a breakthrough in lightweight electricity generators and motors, so that megawatts of electricity can be routed to the fans without losses in efficiency. However, NASA says it anticipates that small, hybrid-powered regional airliners are likely to be operating within the next 20 years.



The N3-X is a similar shape to the B-2 stealth bomber used by the US Air Force

The batteries for the E-Fan are mounted in the wings and contain enough juice for one hour of flight

There are two fans that are each driven by an electric motor

The E-Fan has a wingspan of 9.5m

The plane's top speed is 220km/h (137mph)

TAKING CHARGE

VOLTAIR E-FAN

THE VOLTAIR E-FAN is a tiny electric aircraft powered by rechargeable batteries providing CO_2-free propulsion for training and personal flying. The company is a subsidiary of Airbus and first flew the E-Fan in demonstrations in 2014. The two-seat 2.0 version is planned to fly in 2017, with the four-seat 4.0 following two years later.

Though the E-Fan can only stay aloft for an hour, there is an emerging market for electric-powered light aircraft among customers whose only wish is to fly around their local airfield at the weekend. Electric aeroplanes are quiet and cheap to operate, needing only access to electrical sockets to recharge.

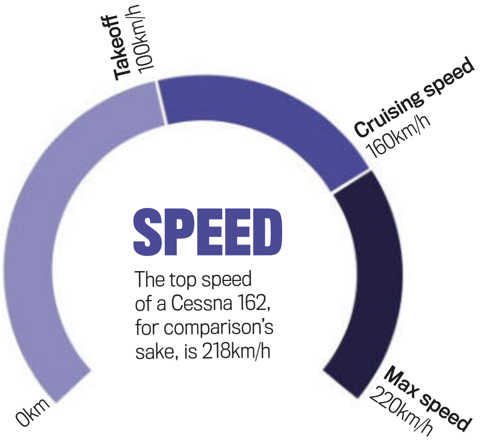
However, Airbus has bigger things in mind. The E-Fan is a means of gaining valuable experience with electric propulsion, and a first step towards hybrid-powered helicopters or even regional airliners capable of carrying as many as 90 passengers. Electric aircraft would allow airlines to reduce carbon emissions and, as they would circumvent noise curfews, they could fly around the clock, says Jean Botti from the Airbus Group. ■

GRAHAM WARWICK works at *Aviation Week* magazine and has more than 30 years' experience in aviation journalism

To read a BBC Future article about the future of supersonic flight, visit bit.ly/flysupersonic

VITAL STATS

THE VOLTAIR E-FAN IN NUMBERS



60kW

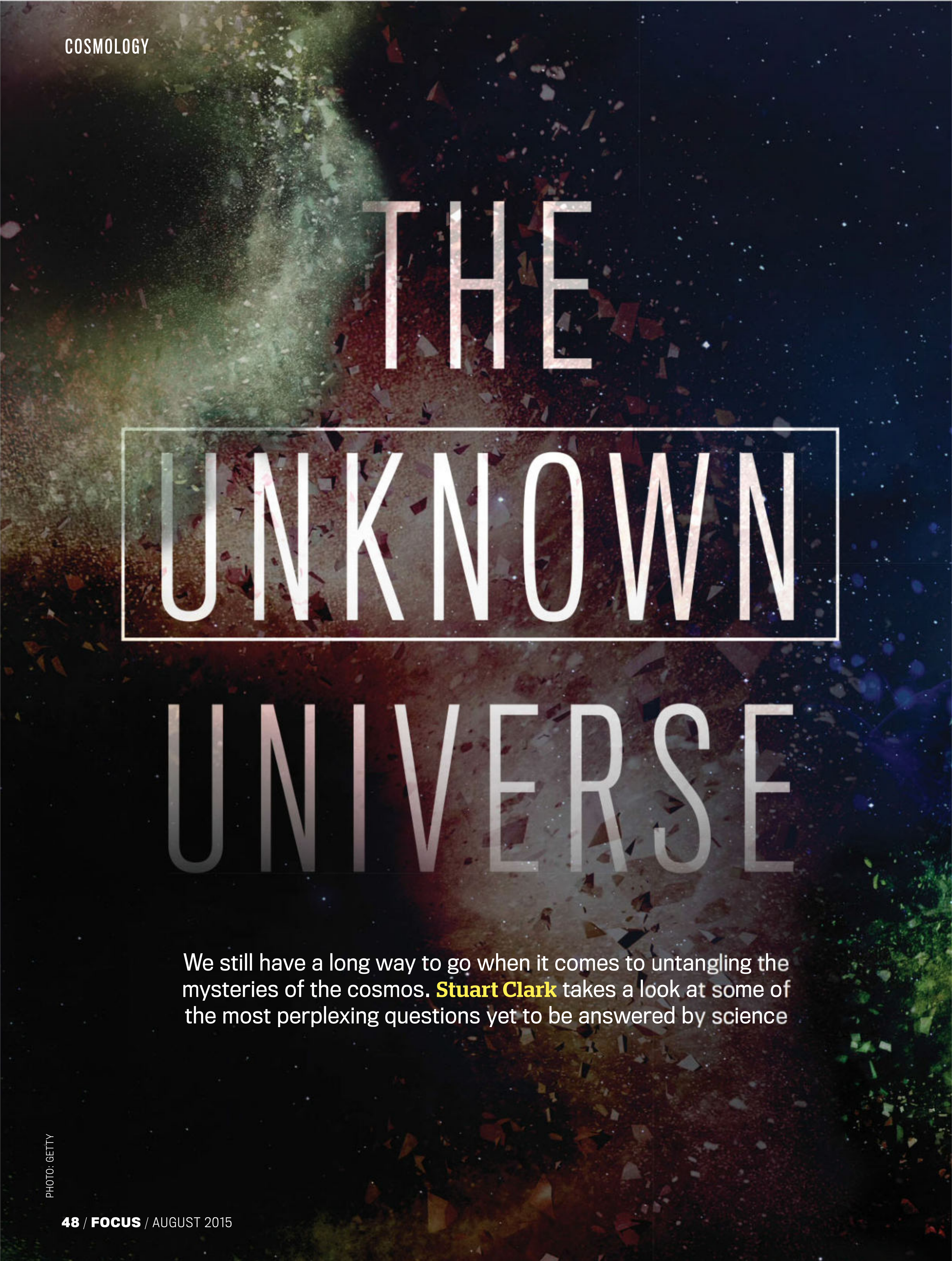
Total power from the two engines

500kg

Unladen weight (with batteries)

1 hour

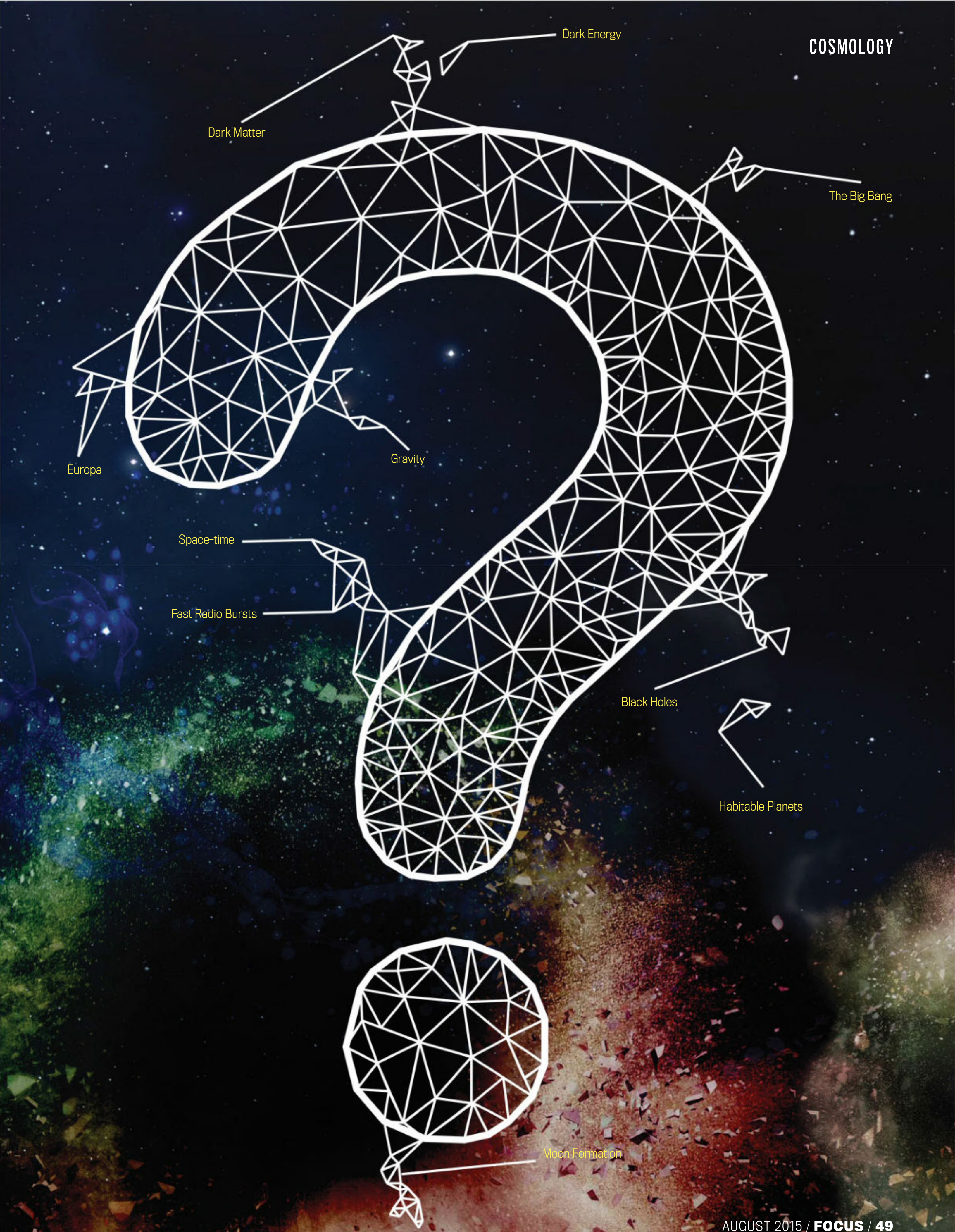
Maximum flying time on one battery charge



THE UNKNOWN UNIVERSE

We still have a long way to go when it comes to untangling the mysteries of the cosmos. **Stuart Clark** takes a look at some of the most perplexing questions yet to be answered by science

PHOTO: GETTY

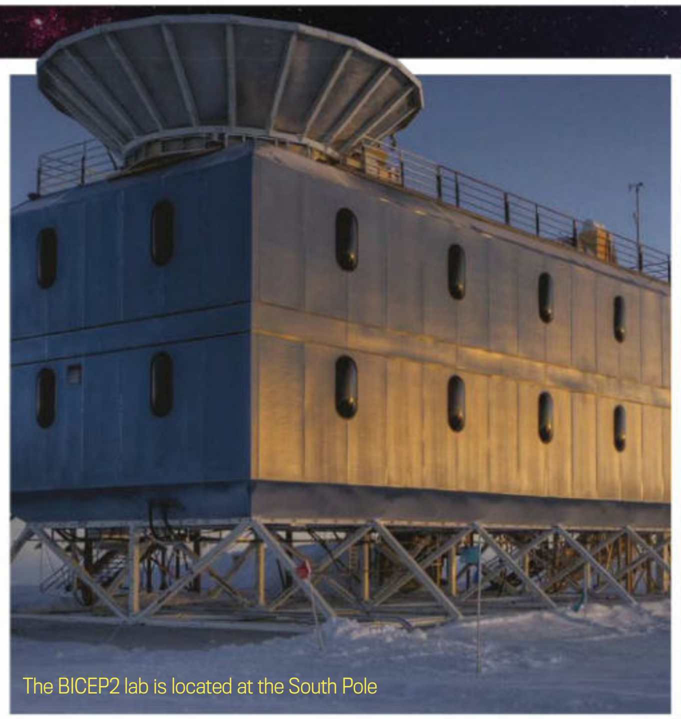

Dark Energy
Dark Matter
The Big Bang
Europa
Gravity
Space-time
Fast Radio Bursts
Black Holes
Habitable Planets
Moon Formation

10

How did it all begin?

COSMOLOGISTS TALK ABOUT the Big Bang, but they have no idea what it was. "We are sure that the early phase of the Universe was hot and dense," says Prof Tim O'Brien, an astronomer from Jodrell Bank, University of Manchester. "But what triggered the Big Bang is still very much open for investigation."

In March 2014, astronomers using an instrument called BICEP2 thought that they had seen evidence for a colossal increase in the expansion of the Universe at the moment of the Big Bang. This would fit theoretical ideas called inflation. Sadly, it turned out to be space dust contaminating the signal.



The BICEP2 lab is located at the South Pole

Magnetars, a type of star, are one proposed source of fast radio bursts

9

What are fast radio bursts?

FAST RADIO BURSTS have the whole radio astronomy community scratching their heads at the moment. Just a dozen or so of the mysterious electromagnetic pulses have been discovered since the first one was detected in 2001. Each lasts just a few milliseconds, yet carries as much energy as the Sun releases in a month. "We really have no idea at all what these things are," says O'Brien.

Various suggestions have been made, including exploding stars, evaporating black holes and even alien signalling devices. Calculations show that there could be as many as 10,000 of these radio bursts taking place every single day, but they still remain a mystery.

8

What is the space-time continuum?

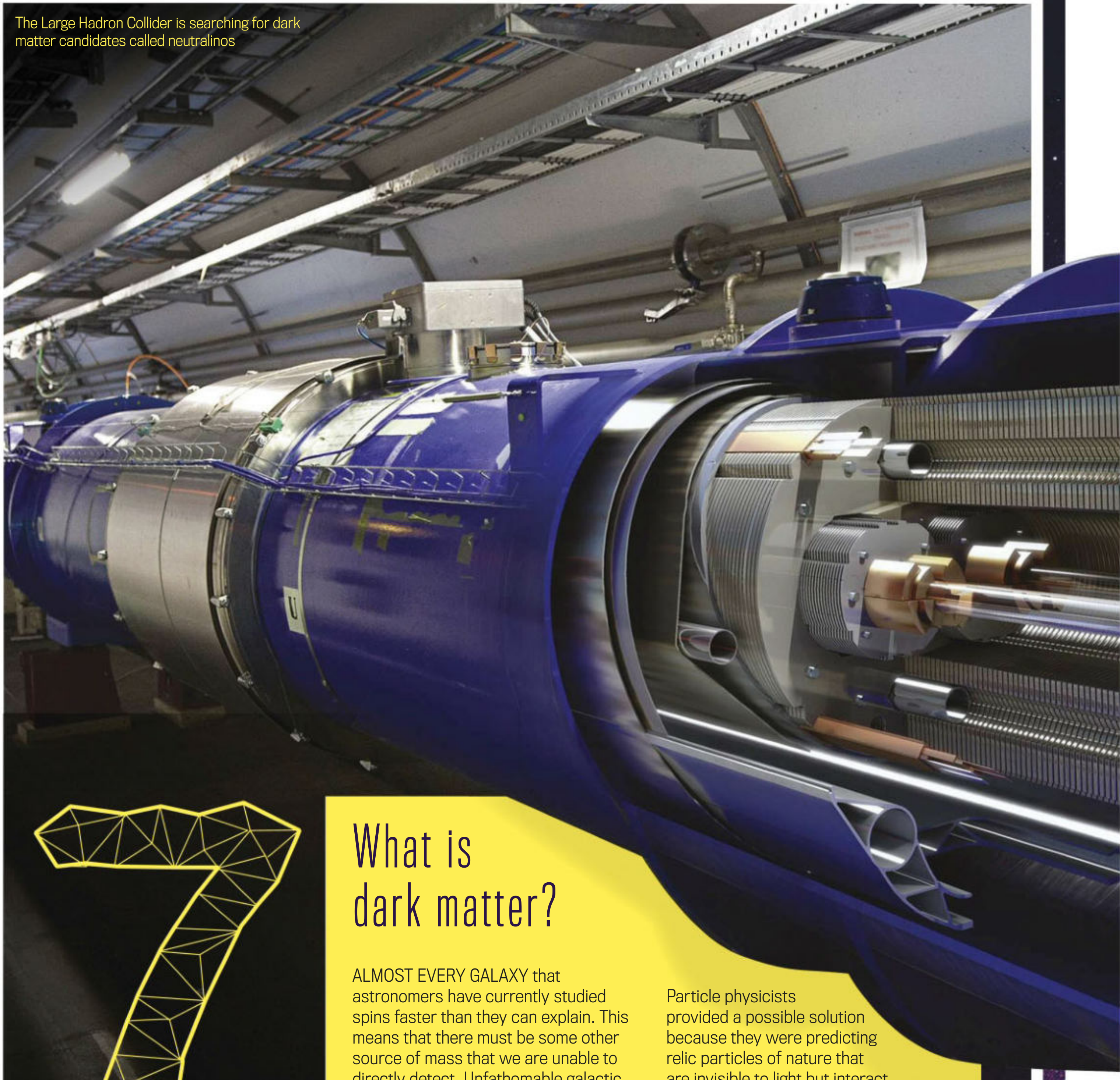
"THE SPACE-TIME continuum is the pinnacle of cosmological achievement in the last century," says Dr Andrew Pontzen, cosmologist at University College London. The trouble is, nobody understands what it actually is. When Einstein developed General Relativity, he introduced it as a mathematical coordinate system. But what did it represent in reality?

The maths suggested it was a malleable substance in which the celestial objects are suspended, but General Relativity provides no real insight into its physical nature. It could be made of incredibly tiny particles like a beach, which looks smooth from a distance but on close-up examination can be seen to be made from grains of sand. If so, it would need a quantum theory of space-time to be developed.

There are some indications that light from distant stellar explosions, known as gamma-ray bursts, are delayed according to their wavelength as they travel across space. This is important because space-time particles would slow down shorter wavelengths of light more than longer wavelengths.

There have been too few observations to prove or disprove the quantum nature of space-time. The puzzle remains: what is the space-time continuum?

PHOTO: STEFFEN RICHTER/HARVARD UNIVERSITY, CERN, NASA



The Large Hadron Collider is searching for dark matter candidates called neutralinos

7

What is dark matter?

ALMOST EVERY GALAXY that astronomers have currently studied spins faster than they can explain. This means that there must be some other source of mass that we are unable to directly detect. Unfathomable galactic motions first came to light in the 1930s thanks to the work of Swiss astronomer Fritz Zwicky. He postulated that the extra mass must come from an unseen gas. He called this gas 'dark matter'.

By the 1970s, the need for dark matter was worse than ever. Astronomers were seeing far too much movement in the individual galaxies, yet they were convinced that the dark matter could not be atoms otherwise they would have found it already. Particle physicists provided a possible solution because they were predicting relic particles of nature that are invisible to light but interact through gravity.

"We are now at a point where a lot of experiments on Earth stand a realistic chance of seeing something," explains Pontzen. One of those experiments is the newly upgraded Large Hadron Collider at CERN, which is now looking for neutralinos. These are currently the best candidate particles for dark matter, but are only hypothetical. If CERN does not find them, it will be back to the drawing board.

6

How did the Moon form?

THE ORIGIN OF the Moon has proven remarkably tricky for astronomers to understand. In the late 1990s, planetary geologists felt that they had finally zeroed in on the answer. They called it the 'Big Splat'.

The idea involves a world about the size of Mars striking the Earth a glancing blow so that the shattered world gathered in Earth's orbit. Once there, the debris coalesced to form the Moon. Moon rocks brought back by the Apollo astronauts corroborated this scenario. But then it all went wrong.

Better measurements showed that the Moon's rocks were not just similar to Earth's rocks – they were virtually identical. This would not be the case if the Moon had mostly formed out of the impactor.

"The giant impact is still the best hypothesis because all the other scenarios just seem impossible," explains planetary scientist Prof David Rothery from the Open University. Currently, researchers are wondering whether a scenario can be envisaged in which the impacting body is smaller and embeds itself in Earth, blasting out rocks to form the Moon.

The Moon could have formed from debris created in an early collision

5

Do we understand gravity?

MANY SCIENTISTS ARE convinced we need a new theory to explain the strongest gravitational fields in the Universe. But a much smaller group thinks that a new theory of gravity is also needed to explain very weak gravitational fields. The idea is called Modified Newtonian Dynamics (MOND). It was developed in the 1980s by the Israeli physicist Mordehai Milgrom. He made a small mathematical modification to Newton's Universal Law of Gravitation and showed that it could reproduce the rotation of galaxies without the need for dark matter. Yet no-one knows why such a modification should exist.

ESA's LISA-Pathfinder mission could help. The craft is designed to test sensitive instrumentation in the study of gravity in space. It's set to launch this autumn, and once the payload has been shown to work, the craft could be sent on a journey to test MOND in a region between Earth and the Sun. LISA-Pathfinder is sensitive enough to show if the weak gravity there is following Newton's or Milgrom's prediction. If Newton rules, there must be dark matter. If Milgrom gets it right, he's looking at a Nobel Prize.

Mordehai Milgrom: Nobel Prize glory?

PHOTO: SCIENCE PHOTO LIBRARY X2, NASA/AMES/JPL, WEIZMANN INSTITUTE OF SCIENCE

4

What makes a planet habitable?

BEFORE WE CAN go looking for habitable planets in the Universe, we first have to know what makes a planet capable of supporting life. This is no easy task. There are a number of factors that determine whether a planet can support life.

Astronomers often talk about the habitable zone: the region around a star in which a planet can be warm enough for liquid water to exist on its surface. However, as Europa proves (see 'Is there life on Europa', p54), this might be too simplistic. "I no longer think about a habitable zone," says Dr Peter Grindrod, a planetary scientist at Birkbeck, University of London. "Instead, I think planetary zones can be much more localised."

What seems clear is that there needs to be an energy source and nutrients, then water or some other solvent in which the biochemistry can take place. In terms of 'life as we know it', this means we should look anywhere there is abundant water and sunlight. But there could be other possible biochemistries as well. A key investigation for theoretical astrobiology is to identify other routes to life as well. Such research has the potential to drastically change the way we think about planetary habitability.

Kepler-22b: snorkel required

3

What are black holes?

"WE'RE SURE THEY exist, even though we've never seen one," says O'Brien. Black holes are the places in the Universe where matter has become so condensed that gravity has become overwhelming. No amount of energy will allow you to escape from a black hole once you cross its outer boundary, known as the event horizon. Light cannot escape either, making them appear black. They are often very small too, which means they are fiendishly difficult to spot. To put this in context, to transform the Earth into a black hole, it would need to be squeezed into a sphere about one centimetre across.

However, the real mystery of black holes is what lies inside them. Nothing in physics appears able to stop the matter collapsing into a denser and denser object until it reaches a point of infinite density in zero volume, known as a singularity. But mathematically, a singularity seems almost impossible. "I find it very hard to believe a singularity can exist in nature," says O'Brien.

Our predominant theories of physics – General Relativity and quantum mechanics – are no help here. Worse, the hints these theories do give are contradictory. Physicists are currently trying to develop 'quantum gravity'. This is a mathematical theory that could give us testable predictions about the true nature of black holes. For now, we're stumped.

An aptly-named black hole. 10/10 for creativity, astronomers...

2

Is there life on Europa?

Graphic derived from space probes showing Europa's water vapour

EUROPA IS ONE of the four moons of Jupiter spotted by Galileo in 1610. At the time, the discovery caused a sensation, with some wondering why such a world had been placed into the heavens. Yet it wasn't until space probes took close-up observations in the 1970s that Europa's true mystery came to light.

Its neighbouring moon, Io, suffers from giant eruptions that throw sulphurous lava high into space. This volcanic activity is sustained by a gravitational tug-of-war that sees Jupiter pulling the moon one way, and the other moons pulling it the other. On Europa, these forces are not so severe. They cannot spark volcanism, but they can keep the moon's interior warm enough to melt much of the ice. Europa's ocean is so large that it must contain two to three times more water than all the oceans on Earth put together.

On Earth, one theory states that life started on the dark ocean floor around hydrothermal vents called black smokers. Black smokers occur when water heated in the interior of our planet jets up into the ocean. The water carries dissolved chemicals that provide nutrients for the ecosystem's exotic microorganisms. Could the same be happening on Europa? Prof David Rothery, a planetary scientist at the Open University, thinks it's a distinct possibility. He says: "Europa is one of the most promising places to look for life. It has everything you need."

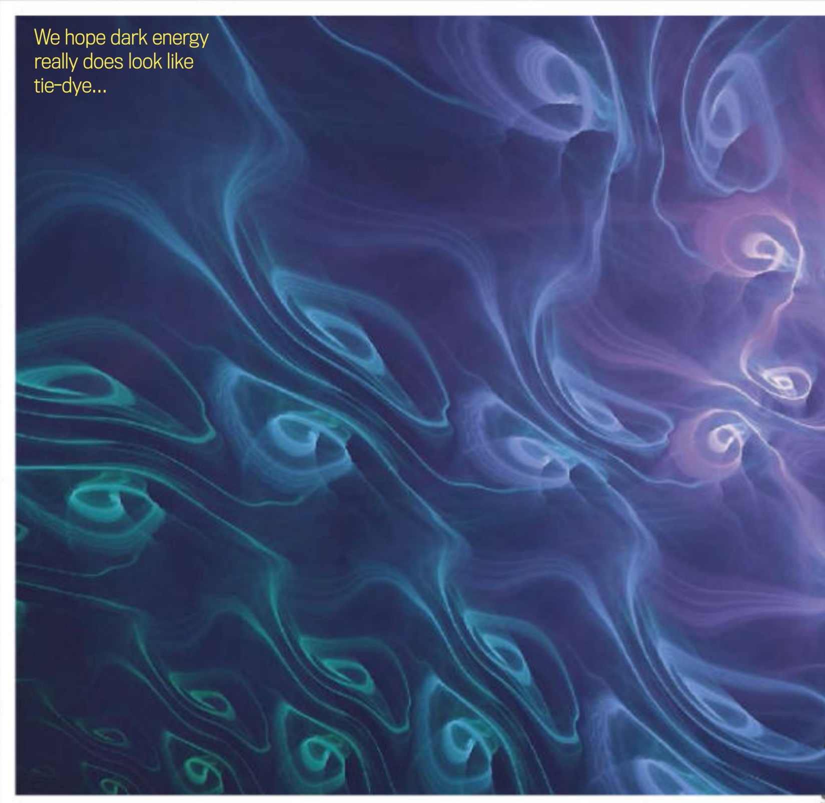
NASA's Europa Clipper mission will determine whether Europa possesses the right conditions for life. There is no precise launch date, but NASA expects it to be on its way in the 2020s. In 2016, \$30m (£19m approx) will be spent developing the craft and its instruments.

In 2012, the Hubble Space Telescope spotted water vapour around the moon's south pole, implying that the ice is thin or fissured, allowing the subsurface water to escape. Planetary geologists have seen cracks appearing on Europa because of the gravitational forces that are at work. All this means that Europa Clipper could directly sample the water by flying through these plumes. Maybe it could look for the evidence of life?

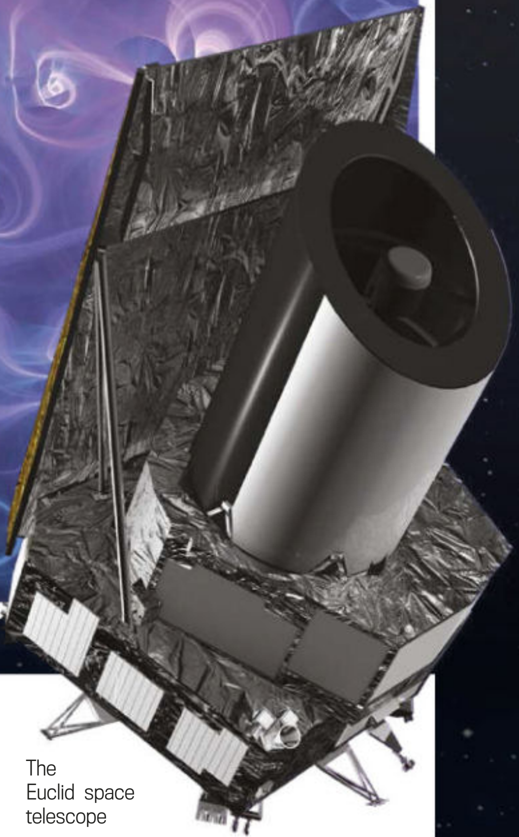
"Once you are at Europa, it is easier to look for life than at Mars," says Rothery. This is because any microbes that have formed in the ocean could find themselves transported to the bottom of the ice crust on the rising currents, and then jetted through the cracks, bringing them to the surface where they could be studied.

Assuming that the signs remain positive for life, a follow-on mission could be designed to land on the icy surface and burrow down into the ocean below.

PHOTO: NASA X2, SCIENCE PHOTO LIBRARY



We hope dark energy really does look like tie-dye...



The Euclid space telescope

1 What is dark energy?

WHEN IT COMES to a list of cosmic unknowns, there is no question about what tops the list. "Dark energy is certainly the biggest mystery in our understanding of the present day Universe," says Pontzen.

In 1929, US astronomer Edwin Hubble established that distant galaxies are moving away from us. Belgian astronomer Georges Lemaître had predicted this behaviour in 1927, when he calculated the expected rate of this expansion. Rather unjustly, this is now called the Hubble Constant.

By the 1990s, the Hubble Space Telescope was in orbit and was being used with ground-based telescopes to measure the rate at which this expansion changed across the breadth of the observable Universe. Two international research teams were racing to make this measurement as it would reveal the fate of the Universe: whether it would expand forever or fall back together, coming to an end in a catastrophic 'Big Crunch'.

It seemed obvious that the expansion must be decelerating, because the gravity generated by the matter in the Universe would resist the expansion. What the teams discovered was the complete opposite – the expansion is getting faster. Further research has shown that the acceleration began about seven billion years ago, when the Universe was about half its current age.

It is as if some previously undetected anti-gravity substance is dominating the behaviour of the Universe. It makes up about 70 per cent of all the matter and energy in the cosmos, and is called 'dark energy'. Yet uncovering its identity remains very difficult. "Frankly, we are still pretty clueless," says Pontzen.

There are two leading possibilities: it is either an energy, or a force of nature. If it is an energy, then it will have to display properties unlike any other energy. Some people call it negative energy, because instead of generating gravity, it creates a kind of anti-gravity. If it is a force, often termed 'quintessence', then it is very weak. But over the vastness of space, it builds up into the acceleration we see around us.

To try to discriminate between these two options, the European Space Agency is building a space telescope called Euclid. Launching in 2020, it will map galaxies to a distance of 10 billion light-years, to reveal the way dark energy has moved them around. It will allow cosmologists to describe the behaviour of dark energy, such as whether it changes from place to place.

Whatever dark energy turns out to be, it will require a re-write of the textbooks when we finally understand its true nature. ■

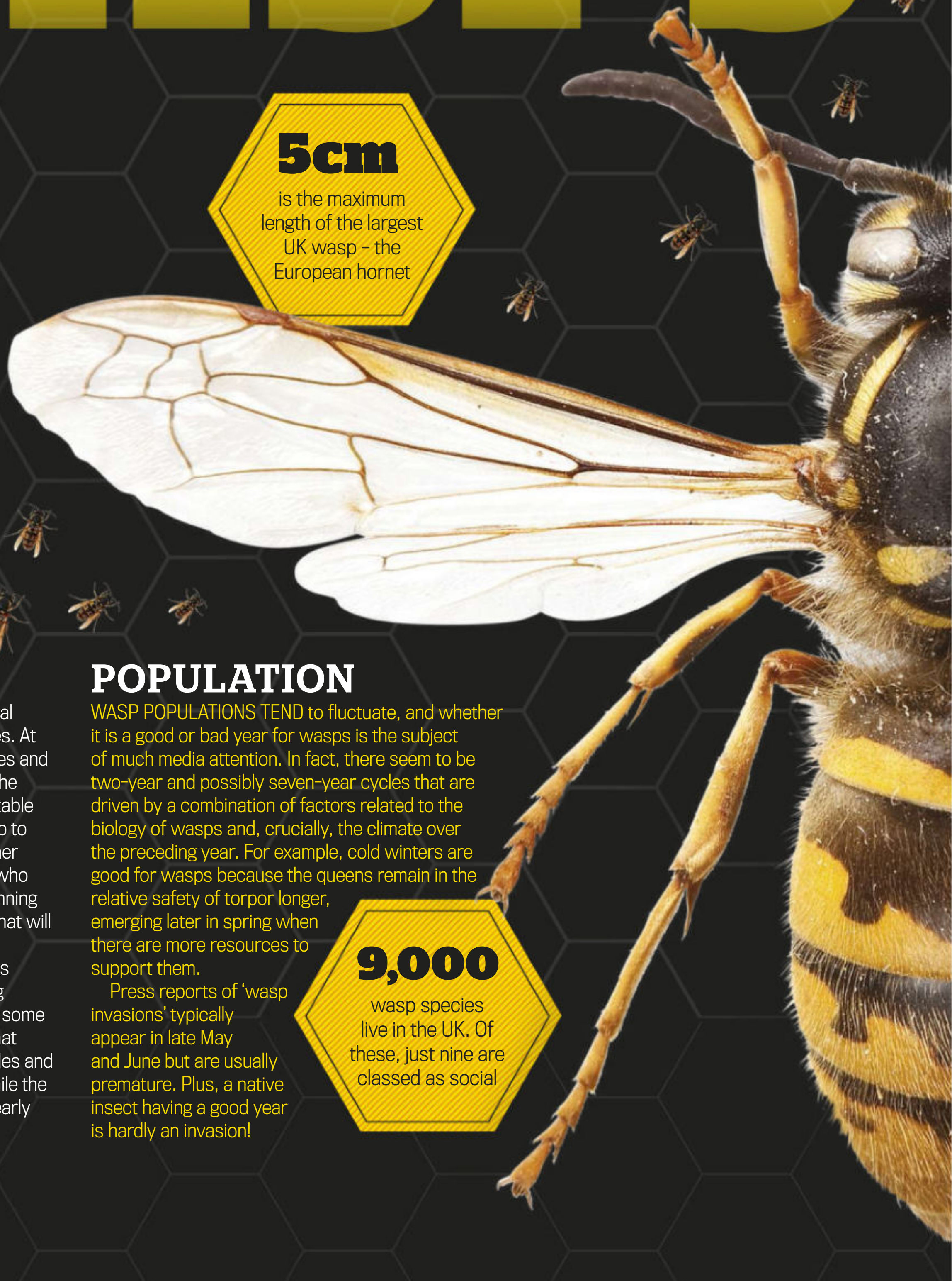
Find out more

To listen to an episode of *The Life Scientific* about dark matter, visit **bit.ly/life_scientific**

STUART CLARK holds a PhD in astrophysics and is author of *The Unknown Universe* – out September 2015

THE SECRET LIVES OF WASPS

Wasps buzz their way into the British tabloids every summer. But **Adam Hart** says that these striped insects are horribly misunderstood...



5cm
is the maximum length of the largest UK wasp – the European hornet

LIFE CYCLE

IN THE UK we are most familiar with social wasps, and they all have similar life cycles. At the end of summer, the queen wasp mates and then overwinters in a state of torpor. In the spring, she wakes up and looks for a suitable place to start a nest. She uses wood pulp to build a small nest in which she can rear her first batch of female workers. Workers, who don't reproduce, rapidly take over the running of the colony while the queen lays eggs that will develop into more workers.

As the season progresses, the workers produce new potential queens by feeding some larvae richer food. The queen (and some workers) can also lay unfertilised eggs that develop into males. The reproductive males and females mate; the queens overwinter while the males die. As the colony winds down in early autumn, the remaining workers also die.

POPULATION

WASP POPULATIONS TEND to fluctuate, and whether it is a good or bad year for wasps is the subject of much media attention. In fact, there seem to be two-year and possibly seven-year cycles that are driven by a combination of factors related to the biology of wasps and, crucially, the climate over the preceding year. For example, cold winters are good for wasps because the queens remain in the relative safety of torpor longer, emerging later in spring when there are more resources to support them.

Press reports of 'wasp invasions' typically appear in late May and June but are usually premature. Plus, a native insect having a good year is hardly an invasion!

9,000
wasp species live in the UK. Of these, just nine are classed as social

PHOTO: PAVEL KRASENSKY/NATUREPHOTO, JELGER HERDER/FLPA

ALIEN INVASION

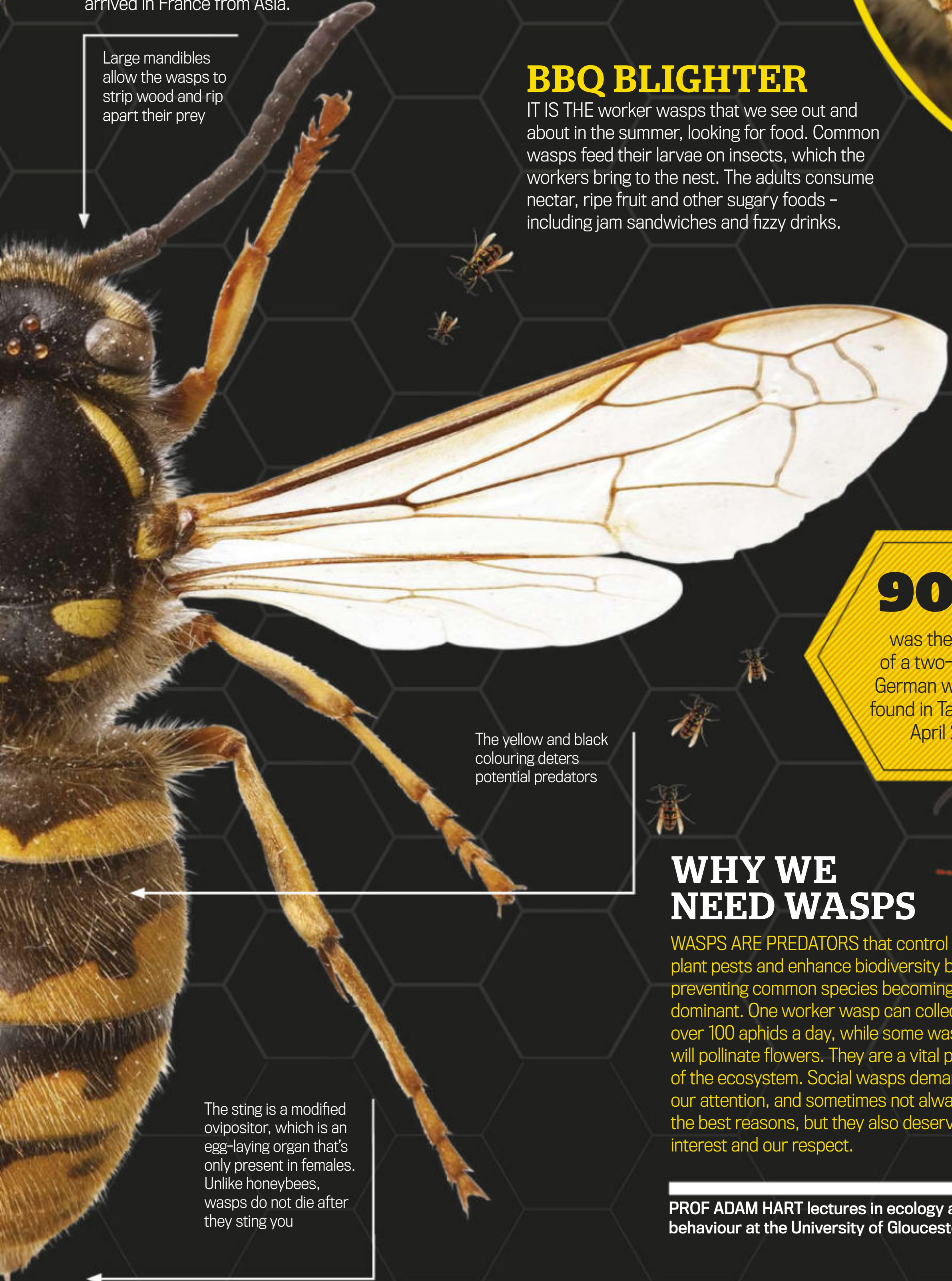
MILD WINTERS COULD mean that colonies start surviving the colder months, continuing to grow and building massive nests. This is already a problem in New Zealand and Australia, which both suffer from introduced wasp species. Meanwhile, climate change could lead to new species reaching the UK. British beekeepers are already on the lookout for the Asian predatory wasp; this bee-killing hornet recently arrived in France from Asia.

WHICH WASP?

THE LARGEST SOCIAL wasp in the UK is the distinctive European hornet. The most likely species you'll encounter is the common wasp (pictured right), but the median wasp, the tree wasp, the Saxon wasp, the German wasp and the red wasp can also be frequently encountered in some areas.

BBQ BLIGHTER

IT IS THE worker wasps that we see out and about in the summer, looking for food. Common wasps feed their larvae on insects, which the workers bring to the nest. The adults consume nectar, ripe fruit and other sugary foods – including jam sandwiches and fizzy drinks.



Large mandibles allow the wasps to strip wood and rip apart their prey

The yellow and black colouring deters potential predators

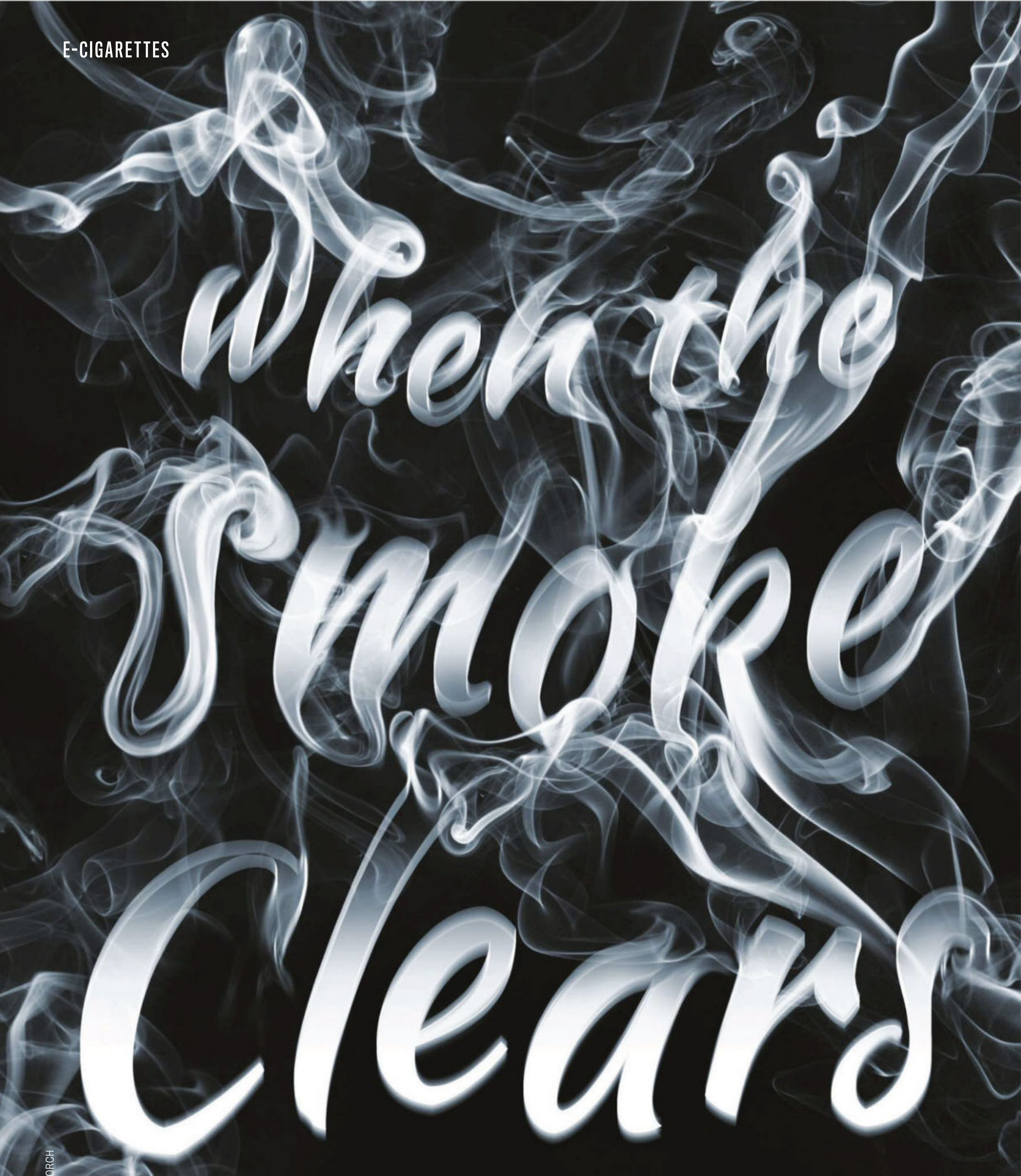
The sting is a modified ovipositor, which is an egg-laying organ that's only present in females. Unlike honeybees, wasps do not die after they sting you

90kg
was the weight of a two-year-old German wasp nest found in Tasmania in April 2015

WHY WE NEED WASPS

WASPS ARE PREDATORS that control plant pests and enhance biodiversity by preventing common species becoming dominant. One worker wasp can collect over 100 aphids a day, while some wasps will pollinate flowers. They are a vital part of the ecosystem. Social wasps demand our attention, and sometimes not always for the best reasons, but they also deserve our interest and our respect.

PROF ADAM HART lectures in ecology and animal behaviour at the University of Gloucestershire



When the Smoke Clears

There are 2.6 million e-cigarette users in the UK – and that number is rising. But are they safe? **Lilian Anekwe** investigates

ILLUSTRATOR: MAGIC TORCH

WHEN THEY FIRST hit UK shops in 2007, electronic cigarettes – or ‘e-cigarettes’ – were hailed in many corners as a healthier alternative to smoking. But nearly a decade on, it turns out things are not so clear-cut. There is mounting evidence that e-cigarettes may come with health risks of their own, and recently the Welsh Government announced plans to ban the smoking of e-cigarettes in public places, with health minister Mark Drakeford insisting they are a “gateway” to tobacco smoking.

The dangers of tobacco use have been well publicised over the last few decades, and lighting up in *Mad Men*-style offices and smoke-filled boozers is now a thing of the past in the UK. But there’s still a clamour to reduce the harmful effects of smoking to individuals and the general public, as well as the costs of cancer and smoking-related lung diseases to the NHS.

A GROWTH INDUSTRY

As a result, the market for electronic cigarettes is growing. A 2014 report by Public Health England found that since the first e-cigarette hit the UK in 2007 the industry has boomed from being worth £91.3m a year to £340m in 2015. In the UK, there are an estimated 2.6 million e-cigarette users – and that number is rising. But years after they were first introduced, we still don’t know for certain what the long-term effects are and whether they are genuinely safe. And experts haven’t reached a consensus on whether their benefits outweigh any possible harm.

The debate hinges on how e-cigarettes work. E-cigarettes are battery-operated devices that simulate conventional cigarettes. They contain a liquid and have a atomiser that’s triggered when a person inhales; this heats the liquid and turns it into a vapour that is breathed in or ‘vaped’. The liquid contains nicotine, the addictive substance in cigarettes, as well as flavourings and chemicals including diethylene glycol, propylene glycol and glycerol. Crucially, e-cigarettes don’t contain or burn tobacco, and therefore they don’t release the cancer-causing chemicals contained in conventional cigarette smoke. So in theory, they should be safer.

Konstantinos Farsalinos, a researcher in toxicology at the Onassis Cardiac Surgery Centre in Athens, studies e-cigarettes from a chemical, not just a theoretical, point of view. “If we as a society are making decisions about whether e-cigarettes are safe, then we need to ask, what do we consider safe?” he says. “We can’t eliminate all the potentially unsafe chemicals from our environment, so we have to come to a working definition of ‘relative safety’ that is defined by the amount and not just by the presence of harmful substances.”

There’s no doubt that e-cigarettes do contain potentially harmful substances, including carbon monoxide, formaldehyde and even trace levels of metals. For example, a study carried out in 2009 by the US Food and Drug Administration (FDA)

> **“E-cigarettes do contain potentially harmful substances, including carbon monoxide, formaldehyde and even trace levels of metals”**

Smoking in offices and other workplaces was banned throughout the UK in 2007

found that e-cigarettes "contained detectable levels of known carcinogens and toxic chemicals to which a user could potentially be exposed". Other studies have found substances that could cause lung and heart problems.

The FDA's safety reporting system recorded 47 so-called 'adverse events' between 2008 and 2013. Eight of these were serious conditions such as pneumonia, heart failure, seizures, low blood pressure and burns caused by battery explosions and fires; mouth and throat irritation, nausea, headaches and coughs were more commonly reported. Of course, smokers can suffer from these too.

But research by Farsalinos and others suggests that the kind of chemicals found in e-cigarettes are generally at much lower levels than in conventional cigarette smoke. A 2013 study in the journal *Tobacco Control* found that harmful chemicals in e-cigarettes occur at levels between nine and 450 times lower than in regular cigarette smoke. Furthermore, Farsalinos's 2014 paper published in *Therapeutic Advances In Drug Safety* found the risk to bystanders who inhale the vapour is minimal.

However, because e-cigarettes are relatively new, there simply haven't been enough long-term studies to know the long-term effects of potential exposure to these chemicals. It's something that researchers including Farsalinos will be looking to shed some light on in the near future. And it's not just the nicotine that needs to be studied. "The flavourings are the most unknown of the knowns," he says. "The compounds in e-cigarettes have been used for many years in the food industry, but we have not assessed their safety when inhaled. We need more specific research – you can't answer these questions with just one or two studies."

MORE RESEARCH NEEDED

Public health groups, including the British Lung Foundation, support the call for more research into the flavourings used in e-cigarettes. The British Lung Foundation says that e-cigarettes "are likely to be much less harmful than conventional cigarettes". But does being less harmful than smoking mean they are safe, or simply the lesser of two risky activities?

David Nutt from Imperial College London is researching the trade-off. His 2014 study in *European Addiction Research* compared the harms, to the user and others, of 12 nicotine products, on a scale of 0-100. Cigarettes had a score of 100. Two-thirds of those points were awarded because of their harm to the user. E-cigarettes scored just four. "Vaping is far safer than smoking cigarettes," Nutt says. "They have overwhelming support from the experts and the Department of Health. But in

E-CIGARETTES LAST LONGER THAN TRADITIONAL CIGARETTES

Konstantinos Farsalinos researches the health impact of e-cigarettes

PHOTO: REX, DELORES JOHNSON / THE NATIONAL ILLUSTRAOR: MAGIC TORCH

E-CIGARETTE LIQUID COMES IN DIFFERENT CONCENTRATIONS (MG NICOTINE/MILLILITRE)

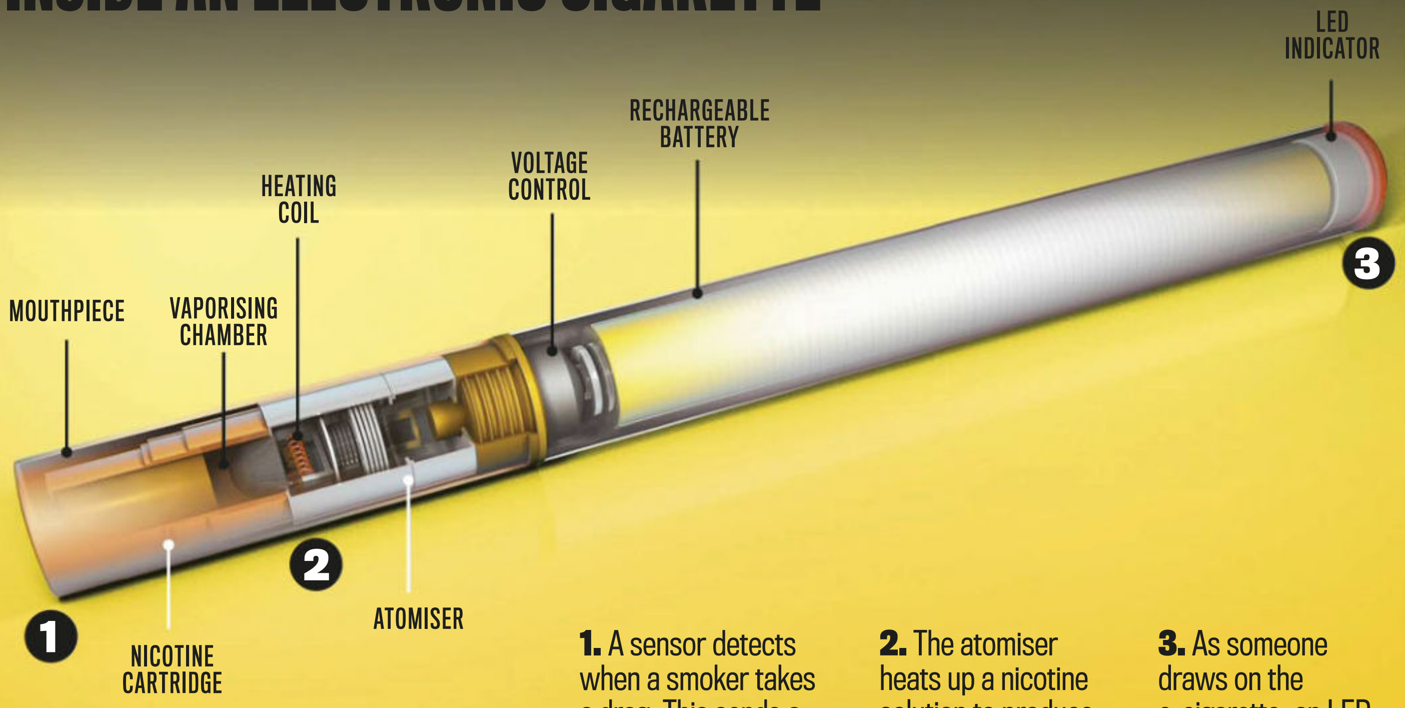
LOW = 6-8mg/ml
MEDIUM = 10-14mg/ml
HIGH = 16-18mg/ml
EXTRA-HIGH = 24-36mg/ml

E-LIQUID VS REGULAR CIGARETTE

1 DROP = 1/2 CIGARETTE
43 DROPS = 1 PACK

MOST E-CIGS ARE RECHARGEABLE VIA USB

INSIDE AN ELECTRONIC CIGARETTE



1. A sensor detects when a smoker takes a drag. This sends a signal to a processor that turns on a heater in the atomiser section.

2. The atomiser heats up a nicotine solution to produce a vapour that can then be inhaled by the smoker.

3. As someone draws on the e-cigarette, an LED light is also switched on by the processor, simulating a flame.

countries that have a large tobacco and lobbying industry there's a big movement to say they're not safe – much of which is scaremongering."

Unlike some of his more noncommittal colleagues, Nutt has already made his mind up.

> **"E-cigarettes are the greatest health intervention since the invention of vaccines"**
>
> David Nutt, Imperial College London

60%

OF SMOKERS ARE SATISFIED WITH E-CIGARETTES, WITH 4 IN 10 USING THEM TO TRY AND QUIT ALTOGETHER

"I think they are the greatest health intervention since the invention of vaccines. Overall, it's way safer than alcohol, and marginally more addictive than caffeine. But the wider public health effects, for the whole population, are huge."

Others are yet to be persuaded. E-cigarettes have been banned in several countries, including Brazil, Singapore, Argentina, and if proposed legislation goes through, in public places in Wales from 2017.

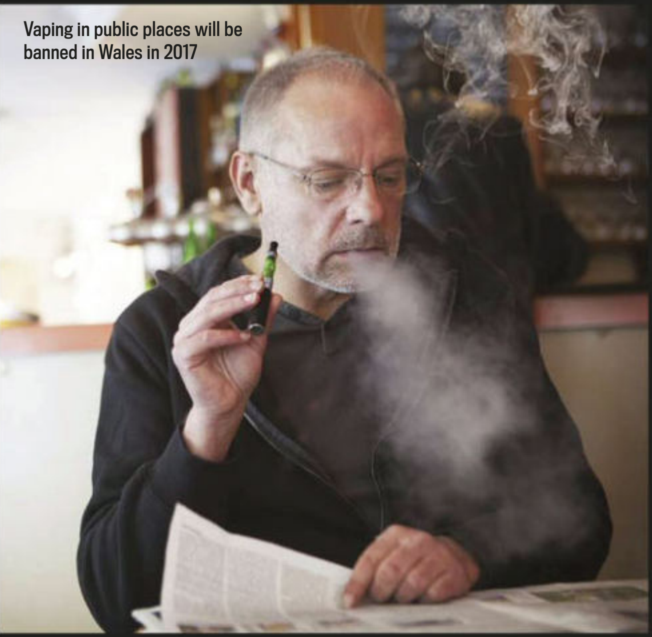
Meanwhile, here in the UK government health agencies like the Medicines and Healthcare Products Regulatory Agency (MHRA) and the National Institute for Health and Care Excellence have weighed in on the debate, both suggesting that e-cigarettes are less harmful than tobacco. However, both the British Medical Association (BMA) and the Royal College of Physicians want to see stronger regulation of e-cigarettes. The BMA says there is a lack of research and evidence in this area to support public health benefits, and Ram Woorthy, deputy chair of its Board of Science, warns e-cigarettes could "reinforce the normalcy of smoking".

A GATEWAY TO SMOKING?

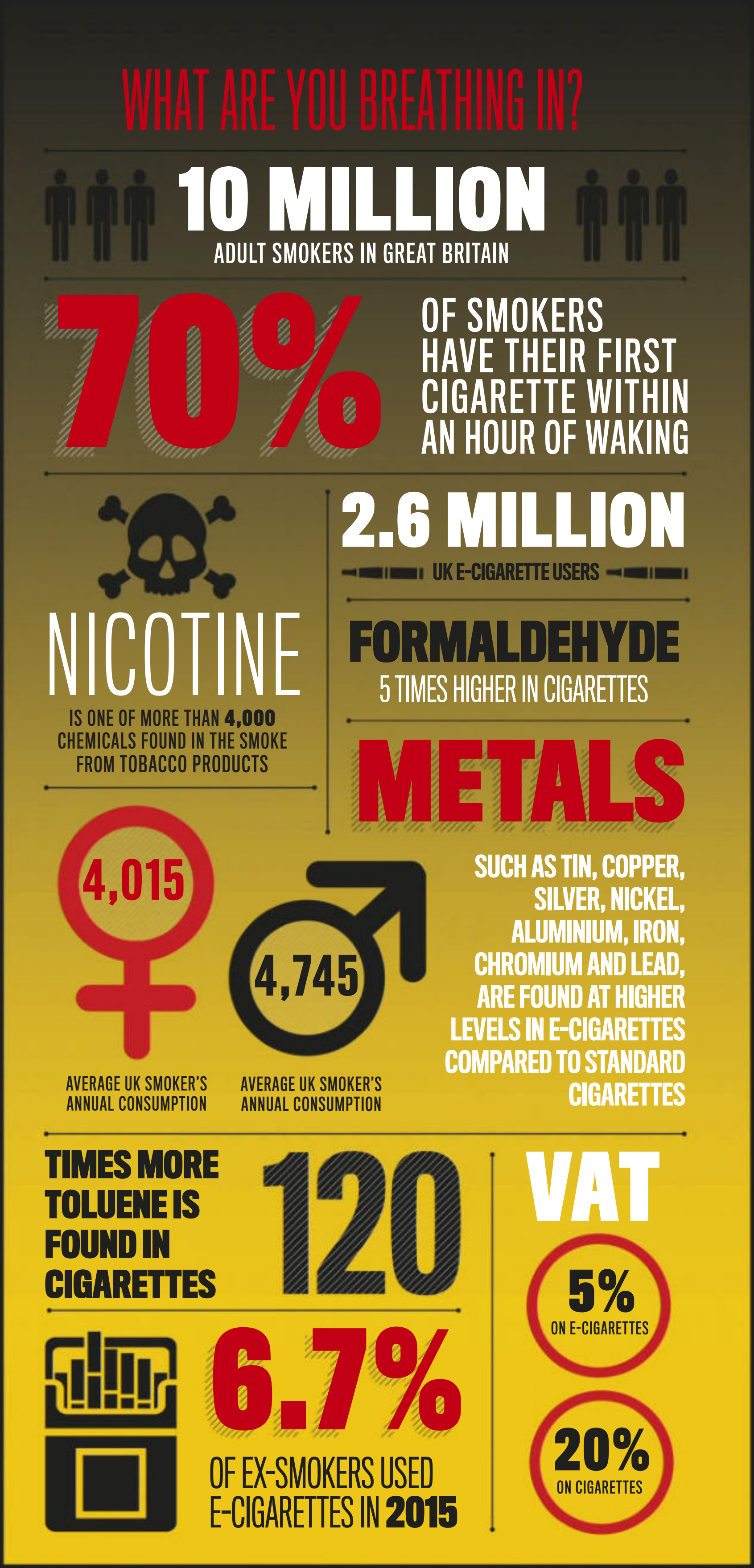
Another concern is that e-cigarettes don't address the problem of addiction. They themselves could indeed be addictive, making them a potential 'gateway' to smoking conventional cigarettes in younger people and non-smokers. Nutt says he believes this is unlikely and, indeed, a Penn State College of Medicine study of 3,500 former smokers who switched to e-cigarettes found vaping is less addictive than cigarettes. However, there is some evidence that non-smokers are trying e-cigarettes, although one of the largest studies – a national survey of more than 75,000 students in South Korea – found that fewer than 1 in 100 non-smokers had used them in the previous month.

This could be crucial in shifting the perception of e-cigarettes to that of a medical tool to help people stop smoking, although they are not licensed for use in this way yet. Fewer people smoke now than in the era depicted in *Mad Men*, but in recent years the proportion of young people who smoke has remained static at 15 to 20 per cent. Stopping smoking is a notoriously tough nut to crack: typically four out of five people fail to quit smoking the first time they try. New tools are clearly needed – but the jury's out as to whether e-cigarettes encourage people to stop smoking, or to start vaping.

PHOTO: GETTY X2



Vaping in public places will be banned in Wales in 2017



WHAT ARE YOU BREATHING IN?

10 MILLION
ADULT SMOKERS IN GREAT BRITAIN

70%
OF SMOKERS HAVE THEIR FIRST CIGARETTE WITHIN AN HOUR OF WAKING

2.6 MILLION
UK E-CIGARETTE USERS

NICOTINE
IS ONE OF MORE THAN **4,000** CHEMICALS FOUND IN THE SMOKE FROM TOBACCO PRODUCTS

FORMALDEHYDE
5 TIMES HIGHER IN CIGARETTES

METALS
SUCH AS TIN, COPPER, SILVER, NICKEL, ALUMINIUM, IRON, CHROMIUM AND LEAD, ARE FOUND AT HIGHER LEVELS IN E-CIGARETTES COMPARED TO STANDARD CIGARETTES

4,015
AVERAGE UK SMOKER'S ANNUAL CONSUMPTION

4,745
AVERAGE UK SMOKER'S ANNUAL CONSUMPTION

120
TIMES MORE TOLUENE IS FOUND IN CIGARETTES

6.7%
OF EX-SMOKERS USED E-CIGARETTES IN **2015**

VAT
5% ON E-CIGARETTES
20% ON CIGARETTES

E-cigarettes can help smokers quit, but is it a case of 'out of the frying pan, into the fire'?

In this regard, the evidence is broadly in favour of e-cigarettes. A 2014 review of studies by the Cochrane Collaboration found that adolescents who used e-cigarettes were twice as likely to have stopped smoking after six months than people given a placebo treatment, and as likely to stop as people who wore nicotine patches. And compared to those who tried a placebo or a nicotine patch, more people who smoked e-cigarettes were able to cut down on cigarette intake by at least 50 per cent.

Hayden McRobbie, a researcher in public health at Queen Mary University, London who led the review, estimated that some 20,000 smokers in England have stopped with the help of e-cigarettes that wouldn't have stopped otherwise. "We can be increasingly confident that e-cigarettes can help smokers to quit," he says. "They may not completely remove the craving for cigarettes but they reduce it, with many smokers going through a period of reduction and dual use before quitting altogether."

It's unlikely we'll be able to absolutely quantify the benefits or harms from e-cigarettes anytime soon, thanks to the complications and timescales involved. However, many smokers remain unconvinced that switching from cigarettes to newer alternatives is the right thing to do for. The researchers, for the most part, are leaning towards e-cigarettes as a healthier option than cigarettes. But for now, the only surefire way of safeguarding your health is not to smoke or vape at all. ■

> **"Adolescents who used e-cigarettes were twice as likely to have stopped smoking after six months"**

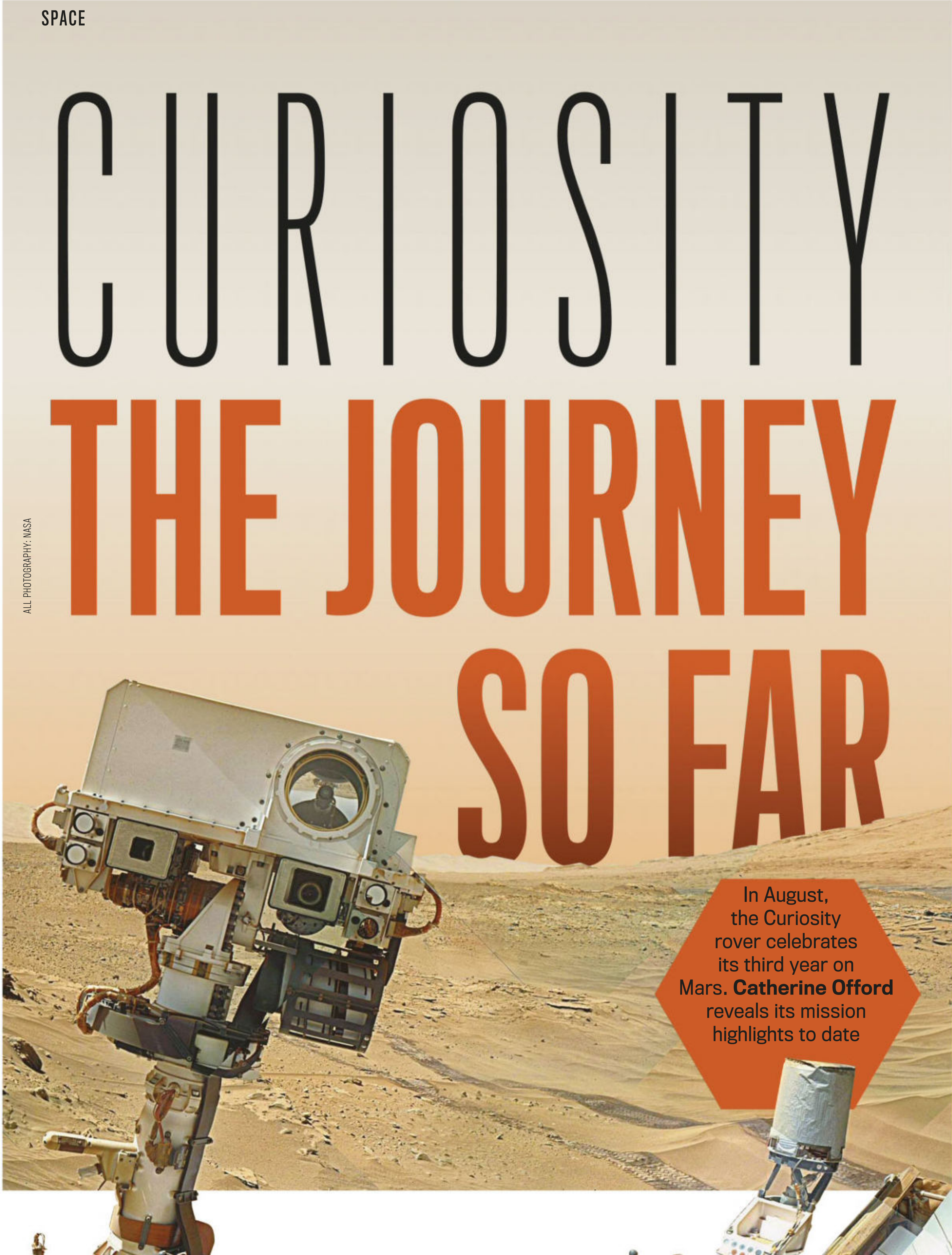
SWITCHING TO **E-CIGARETTES** COULD SAVE THE UK SMOKER UP TO

£48 PER WEEK

LILIAN ANEKWE is a freelance medical journalist and editor of the pharmaceuticals magazine *Pharmafocus*

CURIOSITY

THE JOURNEY SO FAR



ALL PHOTOGRAPHY: NASA

In August, the Curiosity rover celebrates its third year on Mars. **Catherine Offord** reveals its mission highlights to date

1

Aug 2012

LANDING!

After the most complicated rover landing in history, relying on a 'supersonic parachute' and 76 pyrotechnic devices, Curiosity arrives at Gale Crater, Mars. It snaps its first view and sends it back to Earth.

2

Sep 2012

DISCOVERY!

Curiosity takes snaps of a streambed, later named 'Hottah' after the Canadian lake. This prompts speculation that there were once waterways over this part of Mars. Analysis of the streambed indicates that the water was probably between ankle- and hip-deep.

3

Dec 2012

DISCOVERY!

Curiosity finds clear evidence for water on Mars, from soil analysis. It also finds sulphur and chlorine, along with small quantities of organic molecules that are not found naturally on Earth. Concerns are raised about contamination of the testing equipment.

4

Mar 2013

DISCOVERY!

Just weeks after Curiosity tested its drill on the surface of the planet, NASA announces that an ancient Mars could have supported microbes. The first samples contain many 'building blocks' of life, including carbon, hydrogen, oxygen and nitrogen.

5

Apr 2013

HOLIDAY!

Curiosity settles in for a few weeks by itself, as communications are made difficult by Mars moving behind the Sun. But although Curiosity isn't allowed to drive or drill, it can still analyse the samples it has already collected.

6

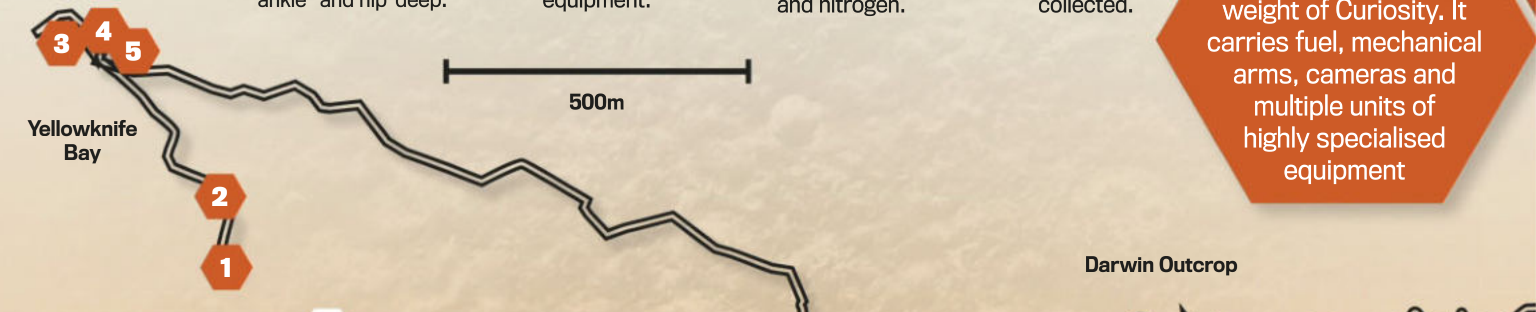
Nov 2013

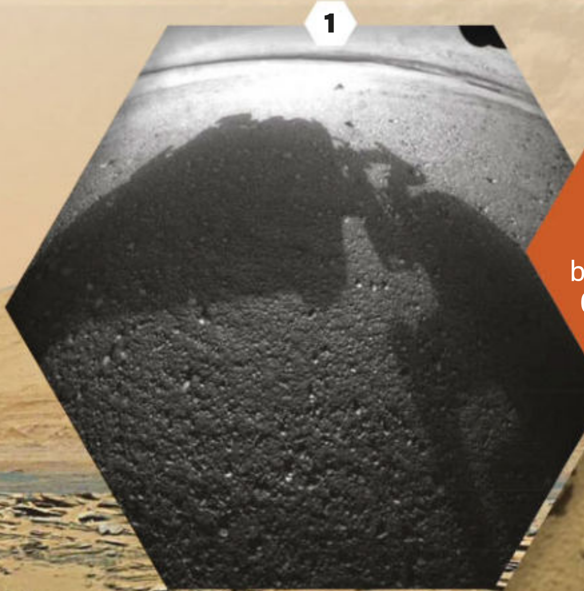
DISASTER!

Curiosity has been travelling across the Gale Crater. It takes some images of its wheels, which show visible damage – probably caused by rocks.

899

kilograms is the weight of Curiosity. It carries fuel, mechanical arms, cameras and multiple units of highly specialised equipment





90

metres can be travelled by Curiosity per hour

Unlike Mars Rover Opportunity, which ran on solar power, Curiosity is powered by the radioactive decay of plutonium fuel that it carries on board

7

Dec 2013

DISCOVERY!

NASA reports that radiation levels on Mars are similar to those on the International Space Station, so Mars visitors might not suffer severe health effects.

8

Jun 2014

ONE YEAR OLD!

Curiosity snaps a selfie at Windjana. The photo celebrates Curiosity's first birthday in Martian years. By now, it has travelled over 10km in total.

9

Sep 2014

PHOTO OP!

Curiosity arrives at Mount Sharp's base, which it will explore over the next few months, gathering data about the planet's geological history. It snaps some pictures of a hole it has drilled.

10

Dec 2014

DISCOVERY!

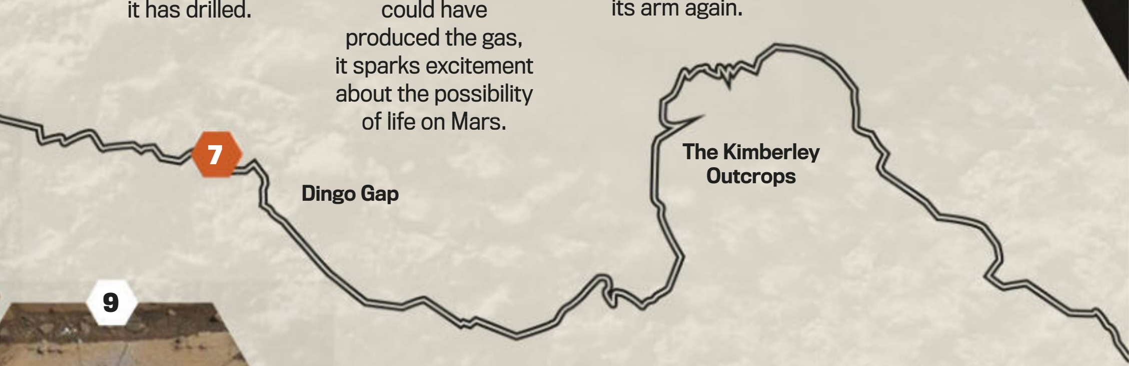
Curiosity detects local spikes in methane, a gas associated with microbial activity on Earth. Although non-biological processes, like reactions between water and rock, could have produced the gas, it sparks excitement about the possibility of life on Mars.

11

Feb 2015

DISASTER!

While transferring a sample, one of Curiosity's arms short circuits. The rover's operations are paused while NASA investigates. A couple of weeks later, Curiosity is sieving rocks with its arm again.



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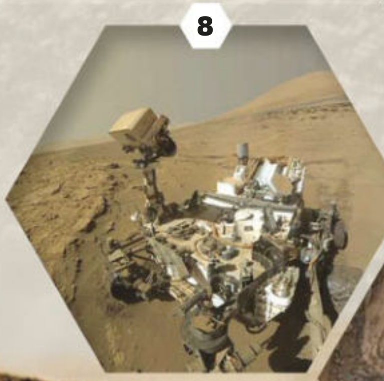

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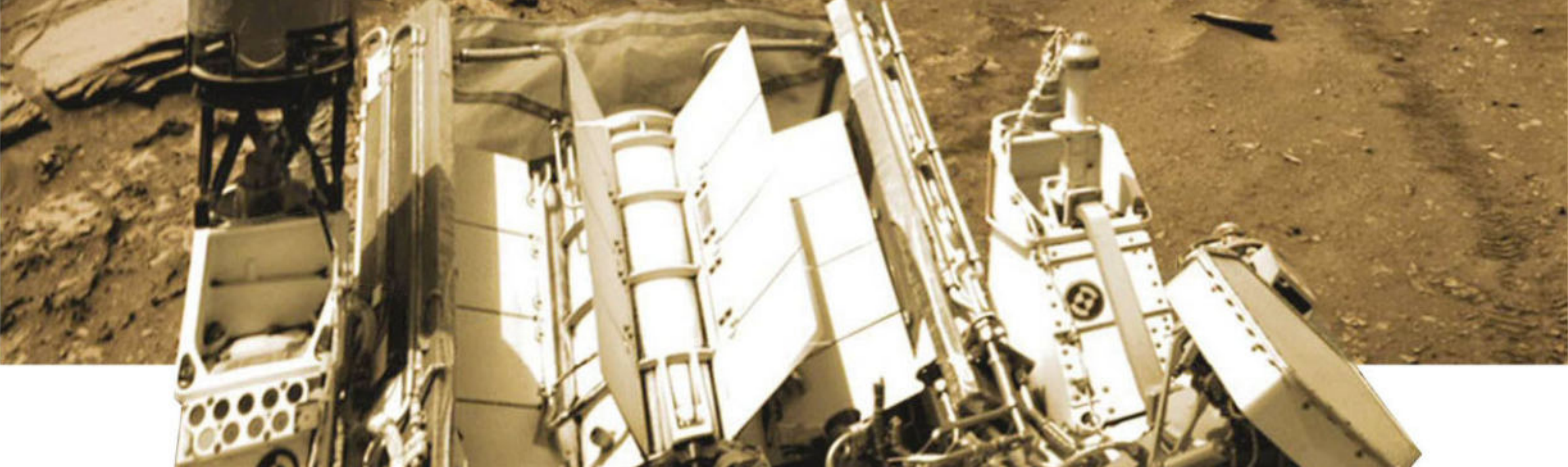
11

Curiosity has already exceeded its two-year life expectancy. Its predecessor, Opportunity, is still going strong since landing in January 2004



12

Apr
2015

PHOTO OP!

Curiosity snaps colour photos of a Mars sunset (pictured left). The Sun appears to glow blue because of 'light scattering' by clouds of dust in the air. The images will help scientists learn more about Mars's atmosphere.

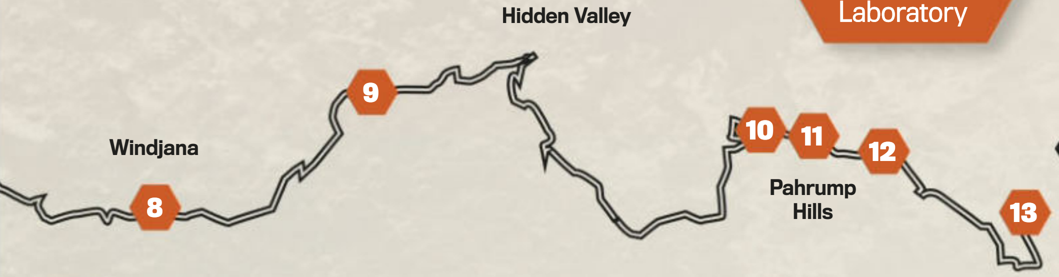
13

May
2015

1,000 SOLS!

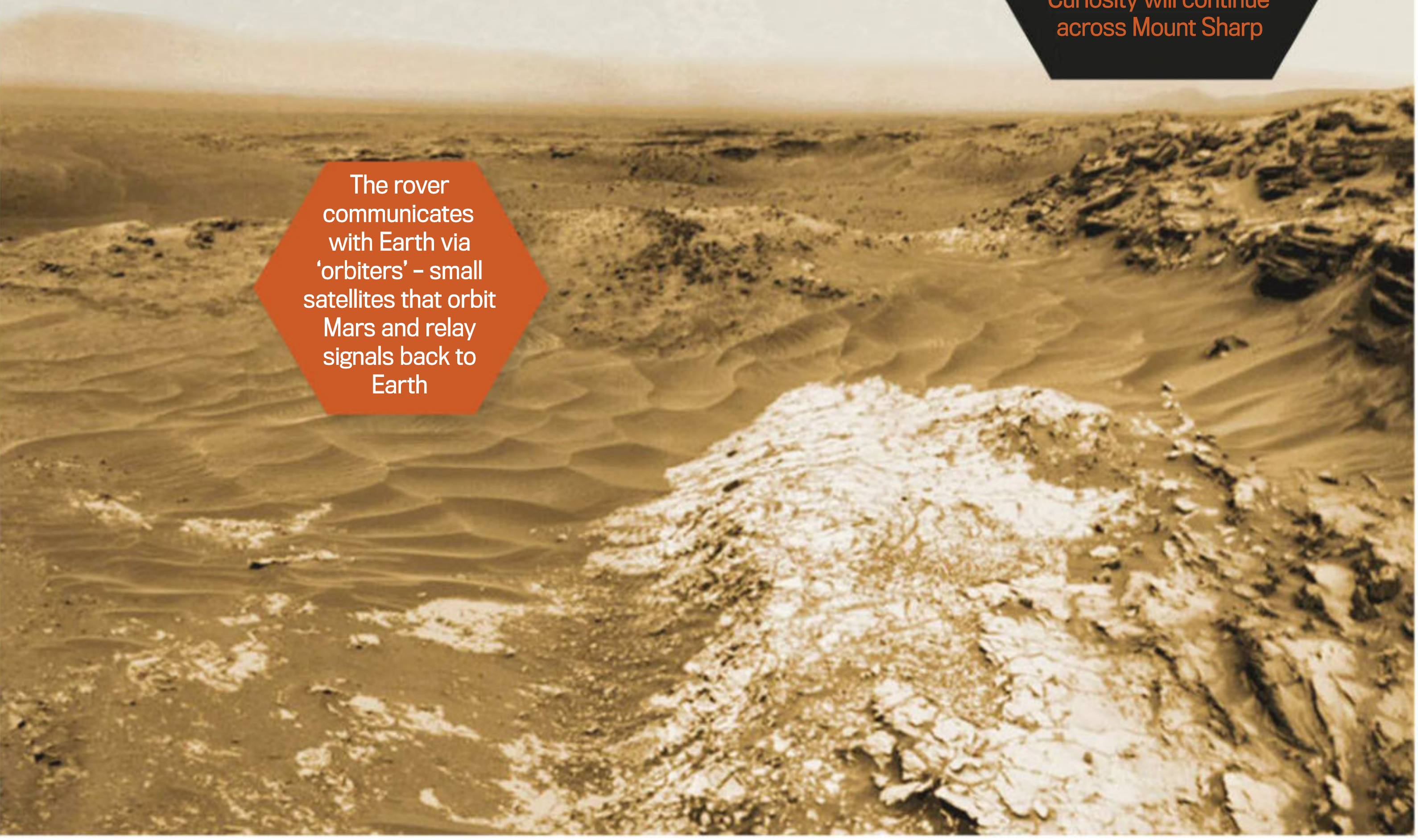
Curiosity celebrates 1,000 Mars days, or 'sols', since it landed. The main image on this page was stitched together from several photos and shows the rover's tracks leading back towards the distant landing site.

$2.5bn is the amount that the Curiosity project cost. The mission is part of the Mars Science Laboratory



WHAT NEXT?

Communication with Curiosity will be interrupted in June 2015 as the Sun will again be between Mars and Earth. When contact returns, Curiosity will continue across Mount Sharp



The rover communicates with Earth via 'orbiters' – small satellites that orbit Mars and relay signals back to Earth

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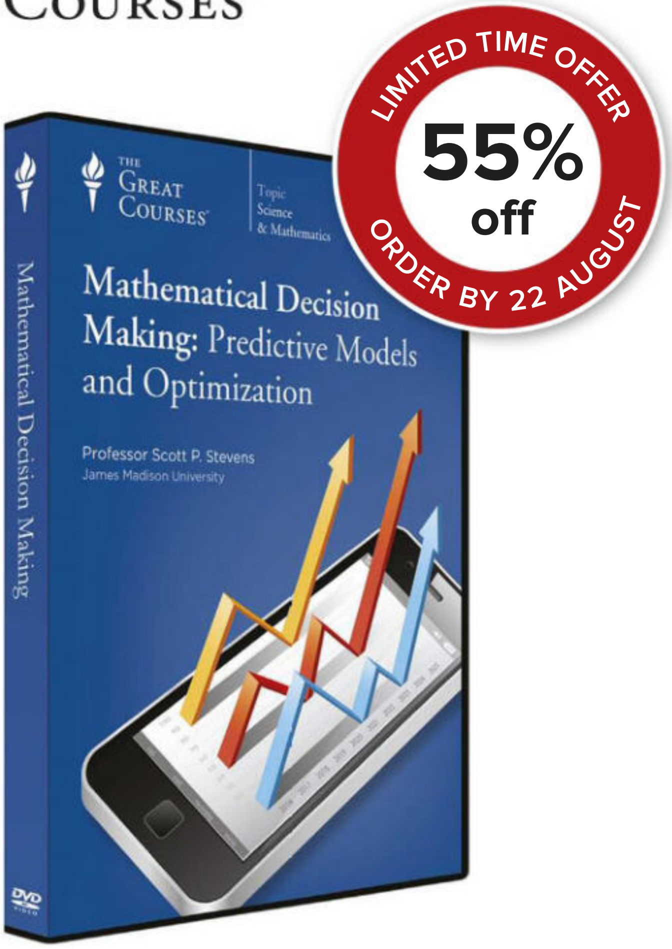
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11. Solving Linear Programs in a Spreadsheet
12. Sensitivity Analysis—Trust the Answer?
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14. Where Is the Efficiency Frontier?
15. Programs with Multiple Goals
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18. Randomness, Probability, and Expectation
19. Decision Trees—Which Scenario Is Best?
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Q&A

YOUR QUESTIONS ANSWERED

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Susan is a visiting psychology professor at the University of Plymouth. Her books include *The Meme Machine*

DR ALASTAIR GUNN
Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester

ROBERT MATTHEWS
After studying physics at Oxford, Robert became a science writer. He's Visiting Reader in Science at Aston University

GARETH MITCHELL
Starting out as a broadcast engineer, Gareth now writes and presents *Click* on the BBC World Service

LUIS VILLAZON
Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

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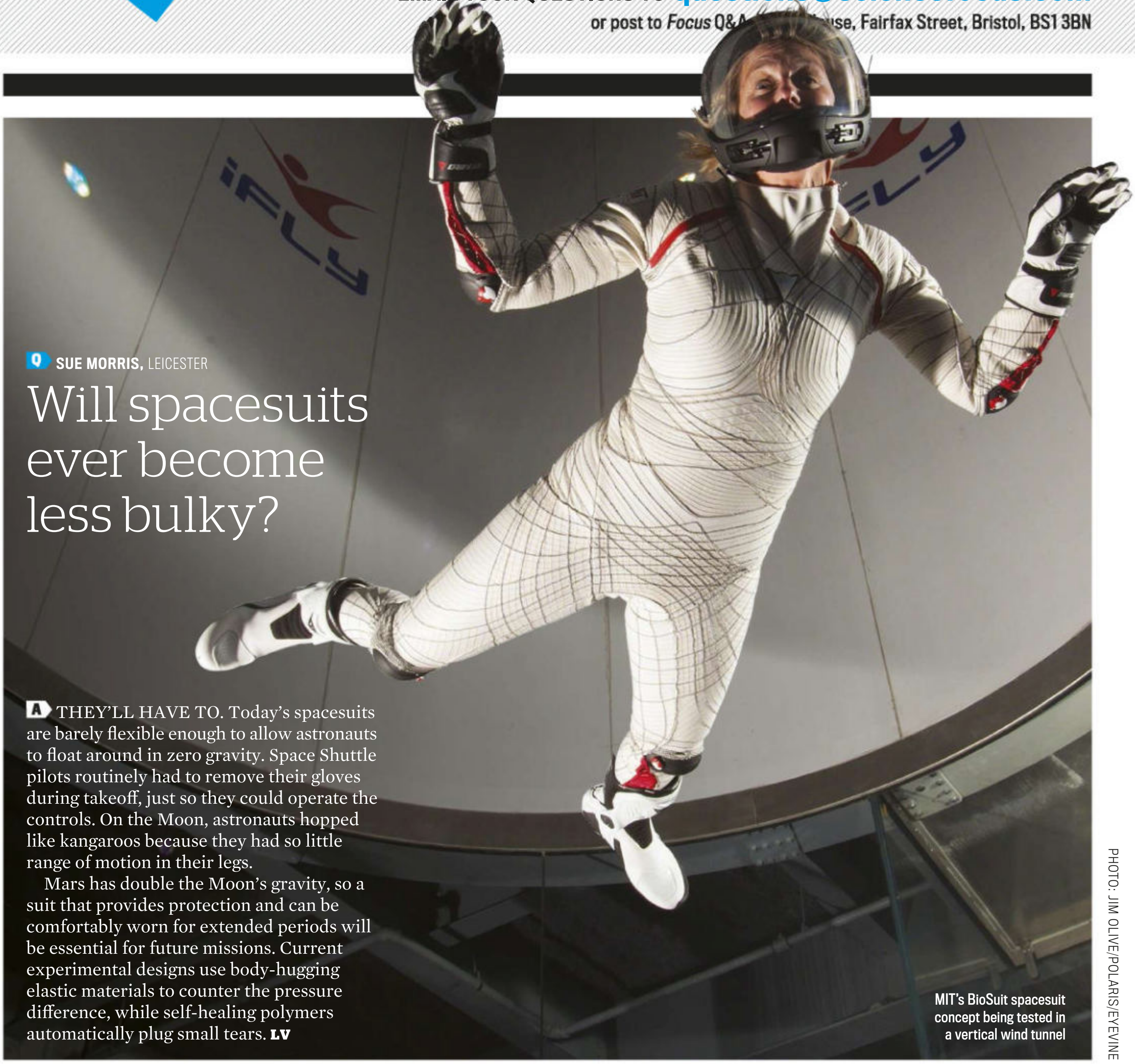


Q SUE MORRIS, LEICESTER

Will spacesuits ever become less bulky?

A THEY'LL HAVE TO. Today's spacesuits are barely flexible enough to allow astronauts to float around in zero gravity. Space Shuttle pilots routinely had to remove their gloves during takeoff, just so they could operate the controls. On the Moon, astronauts hopped like kangaroos because they had so little range of motion in their legs.

Mars has double the Moon's gravity, so a suit that provides protection and can be comfortably worn for extended periods will be essential for future missions. Current experimental designs use body-hugging elastic materials to counter the pressure difference, while self-healing polymers automatically plug small tears. **LV**

MIT's BioSuit spacesuit concept being tested in a vertical wind tunnel

PHOTO: JIM OLIVE/POLARIS/EYEVINE

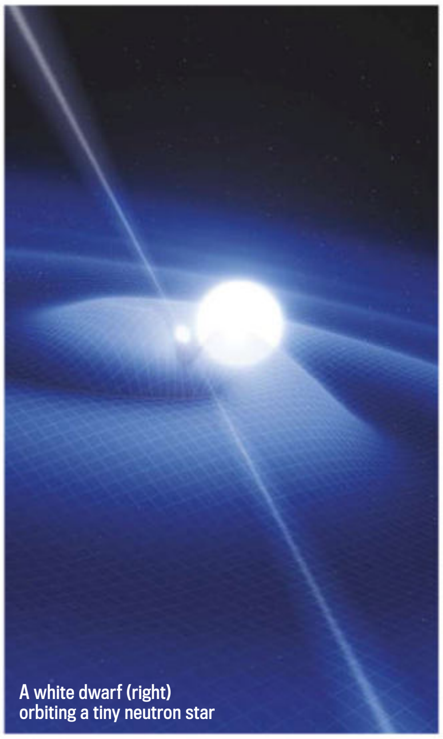
In Numbers

615%

is the amount by which UK hospital admissions for anaphylaxis soared between 1992 and 2012

Q **TONY HERSH,** NEWBURY

Why do white dwarfs take so long to cool?



A white dwarf (right) orbiting a tiny neutron star

A THE RATE AT which energy is radiated by a star (including white dwarfs) is proportional to the fourth power of its temperature as well as its total surface area. The more surface area it has, the more energy it can dissipate in a given time for a given temperature. White dwarfs are very small (similar in size to the Earth), so they cool very slowly.

As a white dwarf cools, its surface temperature decreases which further slows the rate of cooling. This means that white dwarfs will stay warm for billions of years. In fact, they cool so slowly that the Universe isn't old enough to contain any that have cooled off completely to become 'black dwarfs'. By studying the rate of cooling and distribution of temperatures in white dwarfs, astronomers have been able to estimate the Milky Way's age. **AG**

This common drone design might not work on the Red Planet

Q **MIKE LIBMAN,** BRENTWOOD

Would it be possible to fly a drone on Mars?

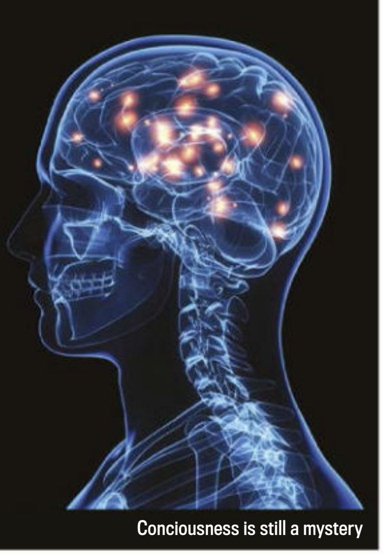
A DRONES COME IN various guises, the simplest being those propelled by electric-powered rotors. And in principle at least, there's no reason why a modified one shouldn't be able to zoom around the Red Planet – though the practicalities are pretty challenging.

An Earth-bound drone is kept aloft by directing air downward, with the resulting thrust counteracting the force of gravity. The good news is that the surface gravity on Mars is barely one-third that of the Earth, so the rotors don't have to work so hard to combat its effect. The bad news is that the Martian atmosphere is far more tenuous than Earth's, with a density 60 times lower. So for a given weight of drone, the rotors must be much more effective at generating the downward thrust. That means increasing the size of the rotors, their number, their spin-rate – or some combination. Doubling the number of rotors and their length might do the trick, but the result would be pretty unwieldy. Then there's the problem of powering the thing: the Red Planet gets less than half the level of solar energy we do. It's all possible, and NASA is looking into it – but perhaps a mini airship design would be more practical. **RM**

Q **STUART LAWS,** NORWICH

How is consciousness physically constructed in our brains?

A IT ISN'T. AT least, if you are thinking of consciousness as a product that's made by the brain then you fall straight into 'dualism' and the 'hard problem' of consciousness. Consciousness is our private subjective experience or 'what it's like to be me'. So the hard problem is how subjective experience arises from an objective body and brain. Mind and brain, or subjective and objective, seem so irreducibly different that nearly all scientists and philosophers agree that dualism cannot work. Somehow, we have to understand consciousness as an aspect of what brains do. If consciousness really is something 'constructed in our brains', no one has worked out how that would happen or indeed what it would mean. Consciousness, even today, remains a fascinating mystery. **SB**



Conciousness is still a mystery

PHOTO: ESO, US AIR FORCE, PETE OXFORD/FLPA, GETTY X2, ISTOCK

QUESTION OF THE MONTH

WINNER!
Sam Leech wins *Utterly Amazing Human Body* by Robert Winston (DK, £14.99)

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UTTERLY AMAZING HUMAN BODY
PACKED WITH POP-UPS! FLAPS AND MINDBLOWING FACTS!

Penguins don't need goggles to see underwater

Q SAM LEECH, AGE 9, BY EMAIL

How do penguins see clearly underwater?

A FIRST, WE NEED to understand a little about our own eyes. In humans, the cornea – the clear surface at the front of the eye – does most of the focusing. The lens only contributes about 10 per cent, and fine-tunes the focus for sharp images at different distances.

Next, we need to look at light. All substances have a refractive index. This refers to the speed at which light travels through them compared to through a vacuum. When we are underwater, the refractive index of the water is too similar to that of our corneas. This means we can't focus as well and our lenses can't adjust enough to make up the difference. Therefore, our vision is blurry underwater unless we wear goggles. Goggles solve the problem because they introduce a pocket of air between the water and our eyes.

Penguins need to be able to see clearly both on land and in water. They have corneas that are much flatter than ours; this takes almost all of the focusing power away from the cornea, so the lens does most of the focusing. To form a sharp image, a penguin's eye must be able to vastly change the shape of the lens. Penguins' lenses are softer than ours and the muscles can squeeze them up against the opening of the pupil to help them focus in the water. Diving birds also use a similar technique when hunting underwater. **LV**

Q KATE DENNIS, MANCHESTER

Why does tape 'screech' when you peel it off?

A SCIENTISTS HAVE BEEN investigating the source of this appalling noise since the 1990s, and have being amazed by the complexity of the phenomenon. Put simply, it's caused when the tape is peeled off at a speed and angle that causes the glue to intermittently stick then slip, creating jagged, unpleasant sound waves. **RM**

One easy way to infuriate your colleagues

Q RON JOHNSON, HARLOW

Why does a banana skin get thinner as it ripens?

A BANANAS ARE A cultivated form of plantain. In the wild, birds and bats are the main seed dispersers of plantains. While the fruit is developing, it is protected by a thick skin that keeps insects out. As the seeds become ripe, the fruit starts to absorb water from the inside of the skin, which causes the cells of the skin to collapse and lose rigidity. This makes it easier for animals to tear them open and carry off the little seeds along with a mouthful of banana. **LV**

Too squidgy for us, but yummy for a bat!

TOP 10

COUNTRIES WITH MOST FACEBOOK USERS

1. United States
Number of users: 152 million
Population: 319 million

2. India
Number of users: 109 million
Population: 1.3 billion

3. Brazil
Number of users: 71 million
Population: 200 million

4. Indonesia
Number of users: 60 million
Population: 250 million

5. Mexico
Number of users: 44 million
Population: 122 million

6. Philippines
Number of users: 34 million
Population: 98 million

7. Turkey
Number of users: 32 million
Population: 75 million

8. United Kingdom
Number of users: 30 million
Population: 64 million

9. Japan
Number of users: 27 million
Population: 127 million

10. France
Number of users: 23 million
Population: 66 million

Q **ROB HAYNES,** LONDON

What's the longest railway tunnel in the world?

A LINE 3 OF the Guangzhou Metro in China has a main branch line that is 60.4km (37.5 miles) long. If you discount urban metro lines, the title goes to the Seikan Tunnel in Japan, which connects the islands of Hokkaido and Honshu. This is 53.85km (33.5 miles) long and is also the deepest rail tunnel in the world, running 100m below the seabed. This record will be beaten next year when the 57.1km (35.5-mile) Gotthard Base Tunnel through the Swiss Alps opens. But both of these tunnels will be eclipsed by the 123km (76.4-mile) Bohai Strait tunnel, which is planned to connect Dalian and Yantai in China by 2023. **LV**

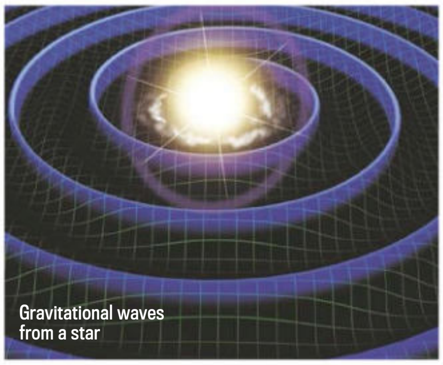
Guangzhou Metro under construction

Q **CHRISTOPHER LINDEN,** POOLE

What could we learn from directly detecting gravitational waves?

A PREDICTED ALMOST A century ago by Einstein, gravitational waves are ripples in the fabric of space and time triggered by massive events like the collision of black holes. Calculations suggest the waves themselves are incredibly feeble. As a result, they're the only major consequence of Einstein's theory of gravity yet to be directly confirmed. That said, it would be little surprise if Einstein proved right – not least because there's already indirect evidence for the existence of gravitational waves from studies of massive neutron stars in orbit around each other.

Much more important would be confirmation that current technology really is capable of detecting the incredibly feeble wobbles predicted when gravitational waves pass through the Earth – amounting to movements smaller than the diameter of a proton. That would encourage efforts to build super-sensitive detectors able to pick up the waves generated by the birth of the Universe – and perhaps, whatever came before. **RM**



Gravitational waves from a star

PHOTO: GETTY X2, SCIENCE PHOTO LIBRARY, JONATHAN RICKARD/EPSRC

Where could the next natural disaster strike?

Around the world, catastrophic events are waiting to happen. **Bill McGuire** reveals where nature is set to wreak havoc next

EASTERN EQUATORIAL PACIFIC

EL NIÑO

In June 2015, Honduras was already showing signs of drought from the El Niño phenomenon

EL NIÑO IS elusive, often threatening an appearance – as reported in this column in spring 2014 – that doesn't materialise. This time, however, it looks as if a whopping El Niño – the name given to the periodic accumulation of unusually warm water in the eastern equatorial Pacific – is definitely on its way. El Niño stirs up the world's weather and spawns a maelstrom of drought, floods and storms. Australian scientists are forecasting that the 2015 El Niño could be as intense the one that occurred between 1982 and 1983, which was blamed for at least 2,000 deaths worldwide. While Australia bakes, Europe and California can expect torrential rains and floods. Perhaps the only saving grace is that the arrival of El Niño invariably acts to put a lid on Atlantic hurricane activity.

NEPAL AND NORTH INDIA

HIMALAYA EARTHQUAKE

Himalayan fault lines lie adjacent to heavily populated regions of northern India

HARD THOUGH IT is to imagine, the magnitude 7.8 earthquake that devastated Nepal in April is pretty small in comparison to the huge quakes that are waiting in the wings. All along the Himalayan Front Fault, which marks the collision zone between the Eurasian tectonic plate to the north and the Indian Plate in the south, enough strain has already accumulated to trigger half a dozen quakes of magnitude 8 or more. One of these is due in the Himalayas, along a segment of the fault between Kathmandu and the Indian city of Dehradun. The region lies adjacent to the intensively farmed Ganges Plain and the teeming cities of north India, including New Delhi. Therefore, the earthquake – when it comes – is forecast to be cataclysmic. Some seismologists have even speculated that it could be the first one to take a million lives.

HONSHU, JAPAN

HAKONEYAMA VOLCANO

Volcanic vapour spews from hot springs in Japan's Lake Ashi region

THE WATER OF Lake Ashi fills two giant calderas, with the largest one exceeding 10km in diameter. They were excavated by eruptions of the Hakoneyama volcano that took place around 50,000 and 180,000 years ago. Now, ominous signs suggest that magma may be on its way to the surface once again. Scientists have raised the threat level to 2 (on a scale of 5), in response to increased seismic activity beneath the volcano and vigorous steaming from hot springs. How big a future eruption will be is anyone's guess. It is even possible that the volcano will return to its slumber. Nonetheless, residents of this popular tourist resort remain on edge.

BILL MCGUIRE is Emeritus Professor of Geophysical and Climate Hazards at University College London and wrote *Waking The Giant*

Got creepy eyes? Become a hypnotist!

Q RICHARD O'NEILL, GLASGOW

Is there any scientific explanation for hypnosis?

A NOT REALLY – AT least, not one that scientists can agree on. Hypnosis has been performed since at least the 18th Century when 'Mesmerism' was said to involve a 'magnetic fluid' or special force called 'animal magnetism'.

This supposedly 'scientific' theory was abandoned when no evidence was forthcoming. In modern psychology, two main theories have long competed to explain the extraordinary effects hypnosis can have. State theorists claim that hypnotic suggestions induce an altered state of consciousness or hypnotic trance in which highly suggestible people are willing to obey the hypnotist and behave in uncharacteristic ways, such as remembering forgotten events, forgetting what they have just done and obeying post-hypnotic suggestions to perform some embarrassing action when given a cue. Non-state theorists claim that all these effects are better explained by role-playing and suggestibility. So there is plenty of scientific research but no agreement as to the best explanation. **SB**

In Numbers

£651m

is contributed to the UK economy by bees, according to the University of Reading. This is because many crops rely them for pollination

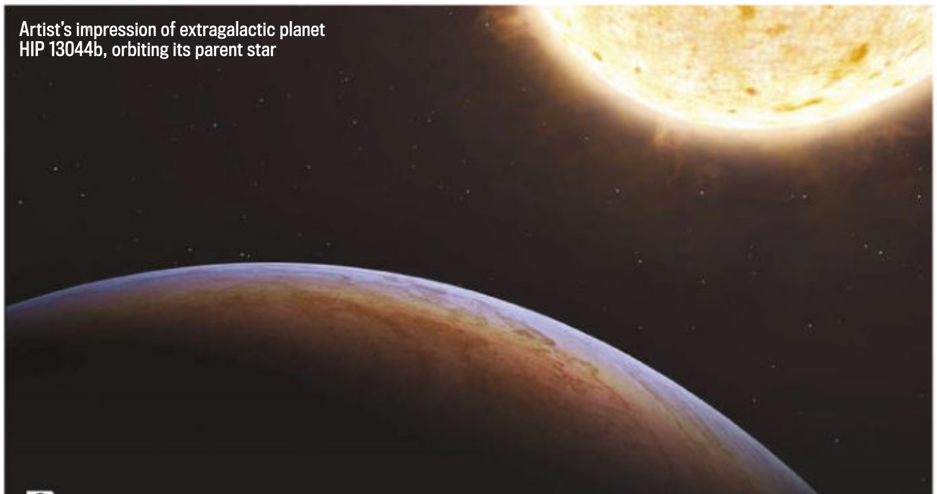
Q LORNA ELLIS, CAMBRIDGE

Can you prevent your phone being hacked?

Great for preventing hackers, not so good for touchscreens

A YOU CAN NEVER completely avoid your phone being hacked. You could stay off the network altogether, but that would defeat the object of having a mobile phone. Even then you are vulnerable to any opportunist who finds your handset lying around.

In the tabloid newspaper phone hacks, imposters accessed victims' voicemails by guessing the appropriate PIN. So being savvy about your voicemail password and changing it from the default is the first step in foiling the hackers. But it's not only about protecting your voicemail, as data on your phone could also be at risk. Avoid storing passwords on the device; if you absolutely have to, do so using a secure app. Another security tip is to switch off the text auto complete function so at least if your phone does fall into the wrong hands, it would be harder to trick the device into betraying your personal info. Finally, steer clear of dodgy apps. **GM**



Artist's impression of extragalactic planet HIP 13044b, orbiting its parent star

Q JACK WATT, ABERDEENSHIRE

How do extragalactic planets form?

A THERE IS NO reason to suppose that the formation process of extragalactic planets [planets located outside our Galaxy] is any different to that of exoplanets found within the Milky Way. That is, they condense from the material in the accretion discs of young stars. Although there are tentative hints of planetary bodies orbiting stars in other galaxies, the only confirmed extragalactic planet is HIP 13044b. This Jupiter-mass planet is orbiting a star that was once part of a nearby dwarf galaxy but has subsequently been swallowed up by the Milky Way. HIP 13044b does throw up one conundrum; its parent star is extremely devoid of heavy elements and such stars don't usually form planets since heavy elements are required to form the dust grains that seed planet formation. There may have been some other process contributing to the formation of HIP 13044b, but it is unlikely to be a result of its extragalactic origin. **AG**

PHOTO: GETTY X4, ISTOCK, ESO

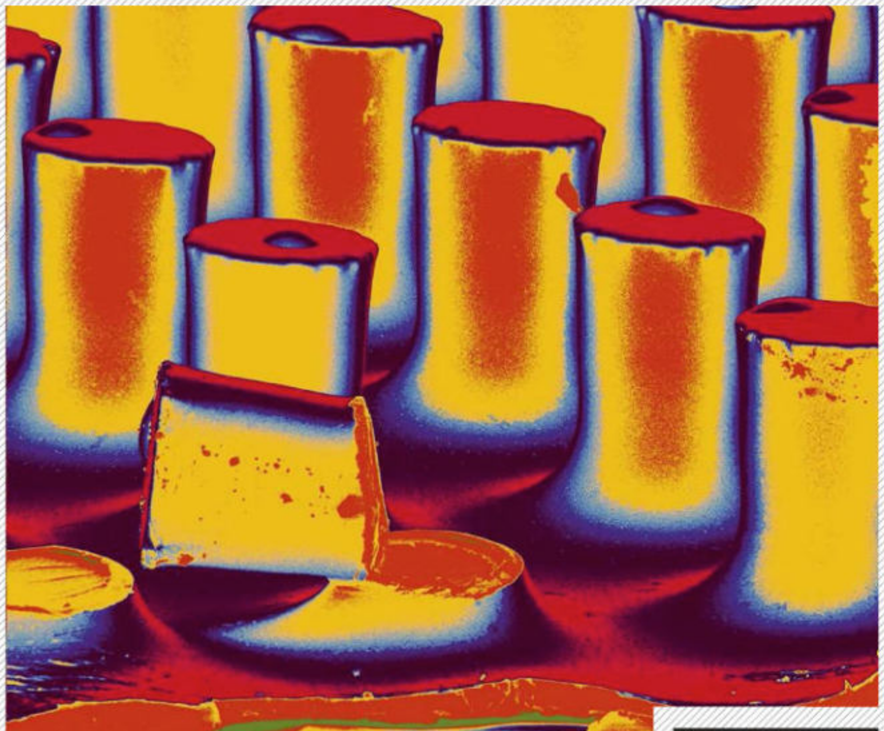
Become an astronaut and get a fat head!

Q ALESSANDRO LOMBARDI, SOLIHULL

What effect does zero-g have on our body's fluid?

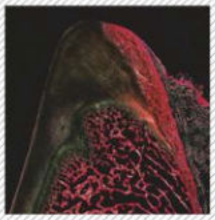
A EARTH'S GRAVITY MEANS that the blood pressure in your feet is about three times higher than in your head. In orbit, this difference disappears and blood pressure is the same throughout the body. When an astronaut arrives at the International Space Station, their head initially has 20 to 40 per cent more fluid and their legs have about 50 per cent less. Receptor cells in the arteries of the upper body detect the extra fluid and incorrectly conclude that there is too much blood overall, so the body removes some extra fluid. Over the course of the first few days, this can amount to a litre of fluid less in each leg! Even after this compensation process, blood pressure in the head is still slightly higher than normal and the pressure on the optic nerve can cause long-term vision problems. **LV**

WHAT IS THIS?



KNOW THE ANSWER?
Submit your guess now at
sciencefocus.com/qanda/what

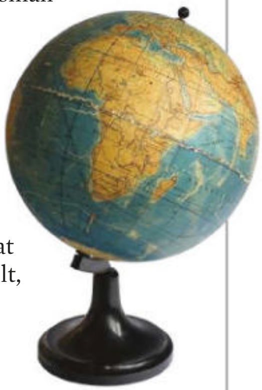
LAST MONTH'S PICTURE →
Dave Taylor correctly guessed a section of human hip bone



Q AMIR MONTAZER, IRAN

Why is the Earth's axis tilted?

A THE EARTH, JUST like all the planets of the Solar System (except Mercury), has a rotation axis that is tilted with respect to its orbit around the Sun. Astronomers propose that this is due to energetic collisions between 'planetesimals'. These small bodies eventually coalesced to form the planets, knocking them off the perpendicular orientation they would naturally have. Uranus is one example of a planet that has a very large axial tilt, which may be the result of a series of such collisions. **AG**



Q ALEX ROUND, LONDON

How does suncream protect you from sunburn?

A OPAQUE SUNBLOCKS ARE effectively paint: inorganic particles of white titanium dioxide or zinc oxide suspended in a heavy oil. The oxide particles form an opaque barrier that reflects visible light and ultraviolet. Clear suncreams use organic compounds, such as phenylbenzimidazole sulfonic acid. This protects from UVB and lets visible light through. Many creams blend inorganic and organic particles to offer good protection. **LV**

Want to avoid looking like a leathery handbag? Make this your best friend...

Q **PETER MOORE,** BANBRIDGE

Can other animals plan ahead?

A YOU COULD ARGUE that when a squirrel buries nuts, it is planning for the winter. But does the squirrel know it is doing this, or is it hard-wired behaviour? These things are hard to test, but experiments with scrub jays have shown that they will stash food in places where they expect to be hungry the next day. Meanwhile, a chimp called Santino living in a Swedish zoo has learned to hide piles of stones in advance so that he can pelt human onlookers to encourage them to move on. **LV**

Why does a squirrel hide its nuts?

This is what happens when you eat too much spicy curry before bed

Q **JAMES SLATTER,** BY EMAIL

How is lucid dreaming possible?

A A LUCID DREAM is when you know, at the time, that you're dreaming. The sensation is like 'waking up' in your sleep. You seem more alert, logical and self-aware and can even take control of the dream. Some lucid dreamers choose to fly and a rare few use the opportunity to meditate. I don't know why lucid dreaming should seem impossible, but it is becoming clearer how it works. Experiments, though difficult, can be done with expert lucid dreamers who signal to an experimenter using eye movements. Their lucid dreams most often occur towards morning, at the end of a period of REM sleep when the brain is more active. Brain scans show the most active areas include parts of the prefrontal cortex and the temporoparietal junction where internal and sensory information come together to form our body schema and self image. This is probably why I feel more awake and 'myself' when I realise I'm dreaming. **SB**

Q **LORENZO MATOUSEK,** OXFORD

How did humans tame wolves?

A WE STILL CAN'T be certain of the time of dog domestication, but DNA evidence suggests that modern wolves and dogs are both descended from a wolf-like ancestor that lived in Europe at the same time as hunter-gatherer tribes, at least 11,000 years ago.

The two main hypotheses are that either wolves domesticated themselves, or they were domesticated by humans. In the first scenario, some wolves hung around human camps to scavenge on bones and leftovers, much like urban foxes today. The hunters would likely only have tolerated the friendlier individuals, driving away or killing the more dangerous animals. This caused the ancestral wolf to split into a tamer subspecies that associated with humans, and a fiercer subspecies that stayed wild. The second scenario involves humans raising orphaned wolf cubs and breeding them. Studies have shown that modern wolf pups can be successfully domesticated from an early enough age. **LV**

"But I wanted a pony, Dad!"

PHOTO: GETTY X3, ISTOCK X3, SIEMENS AG

Q **MIKE JOHNSON,** STEYNING

What is the world's strongest truck?

A THE STRONGEST TRUCK is the BelAZ-75710. It holds the world record for being the largest two-axle dumper truck. It is almost the height of a house, with tyres measuring nearly four metres in diameter. It can shift over 450 tonnes at a time, equivalent to 1,800 motorbikes. It has two 16-cylinder diesel engines dishing out as much power as 20 sports cars via four electric motors. **GM**

Just about the right size to shift the junk off our editor's desk...

Q **BILGE SUTCLIFFE,** NEWQUAY

What causes a halo around the Sun?

A THE APPEARANCE OF a huge, perfectly circular halo round the Sun in Mexico earlier this year sparked rumours of the impending end of the world. In reality, it was the product of sunlight being refracted through hexagonal ice crystals high in the atmosphere. Water droplets can do the same, producing a smaller, more colourful halo. **RM**

Relax - a halo around the Sun is not a sign of the world ending

Q **IAN BERRY,** BY EMAIL

Can you get a computer virus from watching YouTube?

A YOU SHOULD BE safe just watching a video, but be wary of clicking on ads as these can turn out to be malicious. In September 2014, scammers served up dodgy adverts on YouTube and other big sites such as Yahoo! and Amazon. The ads redirected users to a site that detected vulnerabilities in their machine's browser and in applications like Java and Flash. The website then automatically downloaded malware tailored to the computer's vulnerability. **GM**

Q **MARY DEESON,** READING

Why are some people perfectionists?

A BECAUSE OF THE way genes and experience work together. Genetic effects are seen even in newborn babies, whose different temperaments show the beginnings of their personality.

Recent twin studies suggest that personality is more heritable than previously thought. Identical twins are twice as likely as non-identical twins to share qualities such as determination, self-control and a sense of purpose. While perfectionism can be positive, leading to high achievement, satisfaction and self-esteem, it can also be negative with harsh self-criticism, procrastination, disappointment and depression.

Both are related to the 'Big Five' personality traits that sum up our relatively stable adult personalities. These traits are openness, conscientiousness, extraversion, agreeableness and neuroticism. Yet all these traits are subject to the effect of life's encouraging or dispiriting experiences. **SB**

A 'pea-fectionist', if you like...

NEXT MONTH Over 20 more of your questions answered

For even more answers to the most puzzling questions, see the Q&A archive at **www.sciencefocus.com/qanda**

QUANTUM PHYSICS

IN 10 MINUTES

Even Nobel Prize-winning physicists are baffled by this tricky subject. But **John Gribbin** is here to reveal why quantum physics is relevant to all our lives

What is quantum physics for?

Quantum physics may seem like a pretty esoteric topic with no everyday practical value, but that's far from being the case. Quantum physics is the science you need to understand the behaviour of atoms, electrons and light. It therefore underpins the workings of microchips and lasers, among other things. The chemical bonds that hold strands of DNA together, and which enable the double-stranded molecules of the famous helix to unzip and make copies of themselves, operate purely in accordance with the laws of quantum physics. Quantum physics is the science of life: it doesn't get much more basic than that!

Wave, particle or both?

The understanding of physics that scientists had reached by the end of the 19th Century is now called 'classical physics'. It describes the behaviour of the material world in terms of the laws discovered by Isaac Newton, and it describes the behaviour of light and other electromagnetic radiation (everything from radio waves to gamma rays) in terms of the wave equations of James Clerk Maxwell.

Crucially, in the world of classical physics, waves are waves and particles are particles. They interact with one another – as when an electrically charged, jiggling electron emits radio waves – but they always retain their identity. Even the General Theory of Relativity (like its simpler cousin the Special Theory of Relativity) counts as a classical theory, because it retains this distinction between waves and particles, and preserves the idea that changes happen in a continuous fashion.

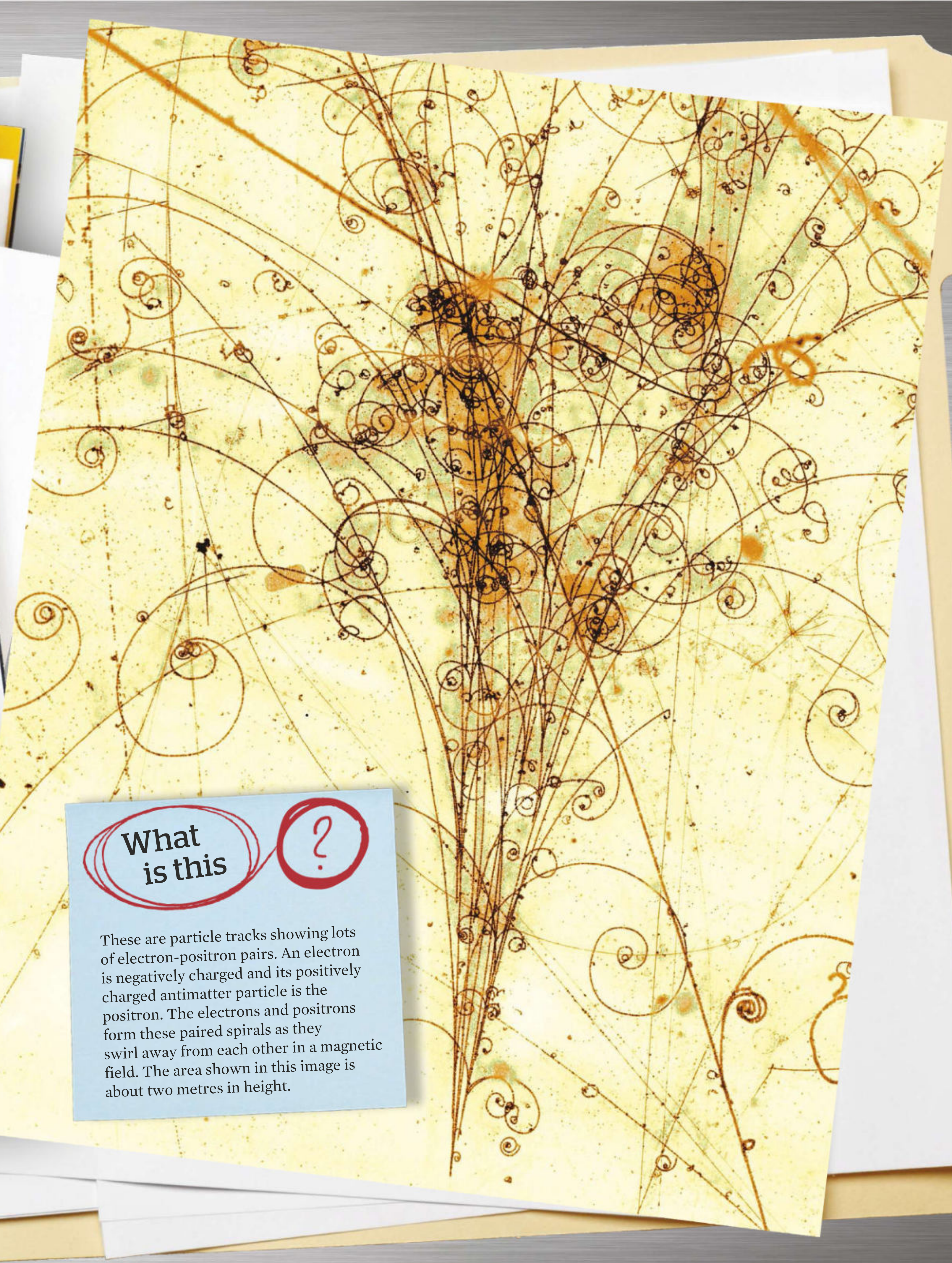
When Max Planck suggested that light was made up of particles, he completely overturned classical physics

PHOTO: GETTY, SCIENCE PHOTO LIBRARY

Quantum physics overturns all of that. The first clue that something other than classical physics was needed came when Max Planck found that he could only explain some aspects of the behaviour of light (such as the nature of so-called black body radiation – see 'Jargon buster' on p82) by treating light as being made up of particles, not a continuous wave. But other experiments still showed light behaving as a wave! Then it was discovered that electrons, which classical physics said were particles, behaved in some circumstances as if they were waves. Wave-particle duality, as it became known, lies at the heart of quantum physics.

Does quantum theory rule?

Wave-particle duality is not the whole story of the split between classical physics and

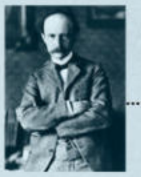


What is this ?

These are particle tracks showing lots of electron-positron pairs. An electron is negatively charged and its positively charged antimatter particle is the positron. The electrons and positrons form these paired spirals as they swirl away from each other in a magnetic field. The area shown in this image is about two metres in height.

TIMELINE

1900



German physicist Max Planck (1858–1947) discovers that black body radiation can be explained if light is emitted in packets of energy, now called photons. This conflicts with the accepted idea that light is a wave.

1905

German physicist Albert Einstein (1879–1955) explains the photoelectric effect, in which light falling on a metal surface makes photoelectrons jump out of the surface.

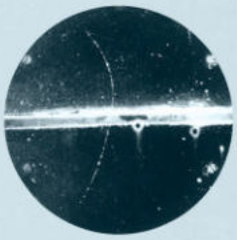
1913

Danish physicist Niels Bohr (1885–1962) explains the spectrum of light radiated by atoms in terms of electrons jumping between fixed energy levels, like steps on a staircase, inside the atom. This is the 'quantum leap'.

1927

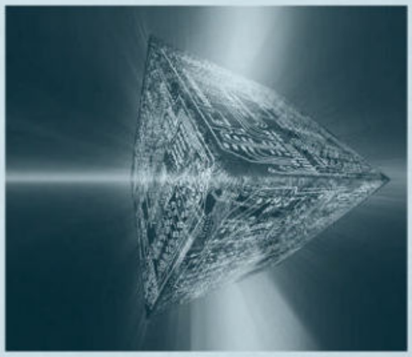
US physicist Clinton Davisson and UK physicist George Paget Thomson (pictured) share a Nobel prize for independently discovering that electrons can be diffracted like waves, confirming the reality of wave-particle duality.

1932



While studying cosmic ray tracks, US physicist Carl Anderson (1905–1991), sees the trace of a particle like an electron but with a positive charge. It is the positron, an antiparticle.

1985



David Deutsch (1953–) publishes a paper pointing out the possibility of making a true quantum computer. He predicts that they will carry out certain tasks much faster than a conventional computer can.

PHOTO: SCIENCE & SOCIETY, GETTY X2, SCIENCE PHOTO LIBRARY X2, NASA AMES/NICK BONIFAS

quantum physics. In the world of classical physics, a particle such as an electron has a definite position in space, and is moving in a definite direction. As long as you make allowance for all the forces it encounters along the way, you can calculate everything that will ever happen to it. This applies to all particles. The classical world is said to be 'deterministic' because once you know where everything is and where it is going, you can work out the entire future and the entire past. Both are determined by the way things are now, which doesn't leave very much room for free will! This is sometimes called 'Newton's Clockwork Universe'.

But according to quantum physics, an electron is *never* located at a precise place (because of its wave nature), and it is *never* sure where it is going. This is the 'uncertainty principle' discovered by Werner Heisenberg, who found there is a trade-off. Quantum objects can either have a relatively well-defined position and a poorly defined direction, or a well-defined direction and a poorly defined position. But they can't have both. It's the price of free will.

This ties in with another key quantum physics idea – probability. You can never say precisely where a quantum entity is or where it is going, but you can use the rules of quantum physics to work out probabilities, such as the probability that an electron will follow a certain trajectory, or the probability that a sample of radioactive material will decay and spit out a particle within a certain time.

What is a quantum?

A quantum is the smallest amount of something that it is possible to have. The smallest amount of light you can have, for example, is a particle called a photon. If you have a bright light, there are many photons streaming outwards. But as you turn the light down, there are fewer and fewer photons. Eventually, there are so few photons that they can be detected one at a time. Astronomers see this happening when they build up images of very faint objects using long exposures of charge-coupled devices (CCDs). When atoms emit light, they do so by rearranging their electrons to radiate energy. Like a ball bouncing down a staircase, the electron jumps from one energy level to another inside the atom, and a photon is emitted. This jump is known as a quantum leap.

A quantum leap is the smallest change it is possible to make – something to remember next time you see the term used in advertising.

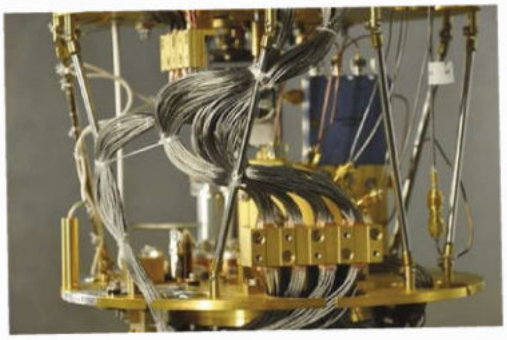
Can we see quantum effects?

The definitive demonstration of quantum effects at work was carried out by a Japanese team in the 1980s. They took the classical experiment which 'proves' light is a wave and adapted it to electrons.

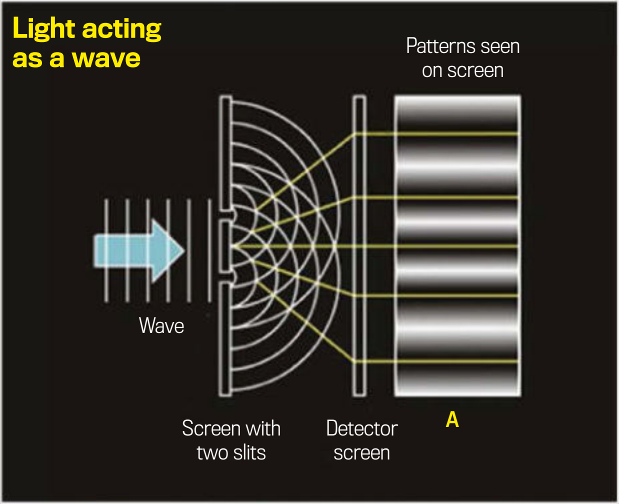
The traditional experiment involves sending a beam of light through two slits in a cardboard screen to make a pattern on another screen on the far side. Like ripples on a pond, the waves

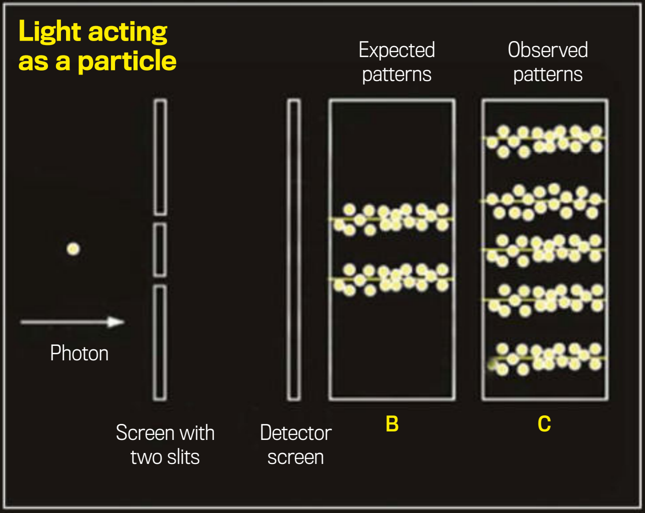
D-Wave

Could this be the first quantum computer? Manufacturers D-Wave claim that it is, but have not revealed details of how it works. What we do know is that it's cooled to temperatures approaching absolute zero. The aim is to develop computers based on the superposition idea of quantum physics. These quantum computers will make classical computers look as primitive as an abacus.



THE KEY EXPERIMENT





IN THE 18TH Century, debate raged as to whether light was a wave or a particle. But in 1803, English scientist Thomas Young showed that, when light is passed through two slits onto a backboard, an interference pattern appears. This is similar to what's seen when two sets of similarly generated waves collide in water (fig **A**). Light, he deduced, must be a wave. In the early 20th Century, however, Einstein and others demonstrated that light can also be seen as a stream of particles, called photons.

This is where things get tricky. When individual particles are sent one at a time through a double slit, as in Young's experiment, they should 'pile up' in two bands (fig **B**). Photons don't, though: even if you send photons through the double slit individually, an interference pattern is observed (fig **C**). Just to complicate matters, if you monitor which slit each photon is going through, the interference patterns are replaced by two bands.

The same applies to other fundamental particles, such as electrons. If that sounds a bit mind-blowing... welcome to the world of quantum physics, where 'wave-particle duality' is commonplace and where the mere act of observing can affect the outcome of an experiment.

JARGON BUSTER

BLACK BODY

An object that is a perfect absorber of radiation is called a black body, hence the name. But if a black body is hot, it becomes a perfect emitter of radiation. So, seemingly paradoxically, the Sun is an almost perfect black body radiator.

DIFFRACTION

This is the process by which waves can bend around corners or spread out in all directions from a small hole or slit.

DUALITY

This is the way that quantum entities seem to be both particle and wave. Light 'waves' are associated with particles called photons; electron 'particles' are associated with waves.

ENERGY LEVEL

A quantum state, for example in an atom, that is associated with a particular energy. Electrons in atoms will sit on, or occupy, specific energy levels.

QUANTUM LEAP

The change of a quantum system, such as an electron in an atom, from one energy level to another. This happens without the system (electron) passing through any in-between state.

SUPERPOSITION

This is when a quantum system exists in a mixture of states. For example, an electron has a property called spin. On its own, the electron is in a superposition of spin up and spin down. It only 'collapses' into one state when it interacts with something. This is linked to the idea of quantum probability – there is a 50:50 chance of finding the electron in either state.

PHOTO: SCIENCE PHOTO LIBRARY X3

started to spread out from the two slits and interfered with one another to make the distinctive pattern. In their variation on the theme, the Japanese team fired electrons, one at a time, through an equivalent setup onto a screen like a television screen, where each electron made a single spot as it arrived, showing that it was a particle. But as hundreds of electrons were fired through the experiment, one after another, the pattern of spots that built up was an interference pattern, proving that electrons are waves.

Don't worry if you find your mind boggled by this. The physicist Richard Feynman used to say that "nobody understands quantum physics" – and he had a Nobel Prize for it.

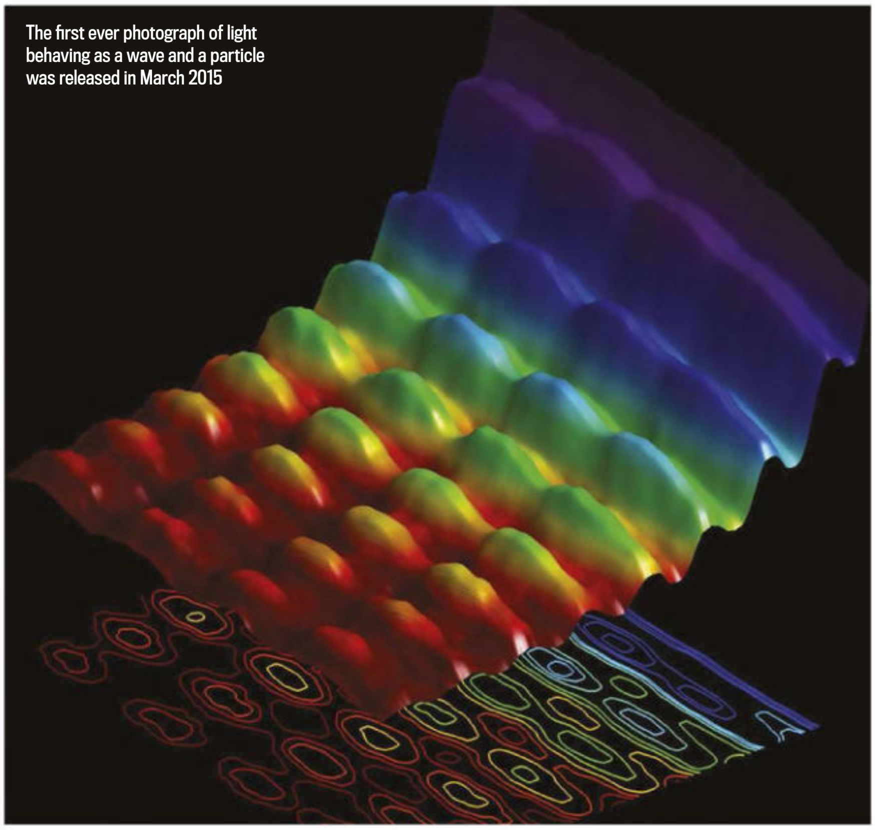
Are there practical applications?

Applied quantum physics is everywhere around us. Computer chips, including the ones in your smartphone, are designed using quantum physics and operate on quantum principles. The lasers used to read Blu-ray discs operate on quantum principles that were first worked out by Albert Einstein 100 years ago. Physicists have developed tools known as superconducting quantum interference devices, or SQUIDs, in which electron waves travel round a ring of metal about the size of a wedding ring. These are supersensitive detectors of magnetic fields, and are used in many different applications including the MRI scanners with which doctors can 'see' inside the human body.

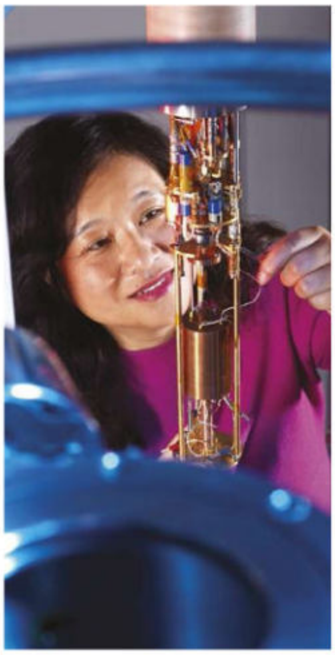
The most exciting application of quantum physics today is in the new field of quantum computing. Ordinary computers are based on switches that can be either on or off (0 or 1); in contrast, a true quantum computer has switches (single atoms or electrons) that can be both on and off at the same time. This is a so-called superposition, which makes the computer immensely more powerful.

How does quantum physics explain the Sun's energy?

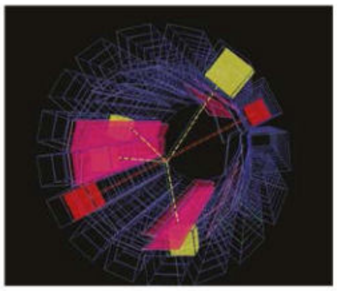
Stars like the Sun release energy as a result of a process called nuclear fusion. At its simplest, inside the Sun two protons (hydrogen nuclei) come



The first ever photograph of light behaving as a wave and a particle was released in March 2015



Researcher adjusting NanoSQUID device that changes temperature when hit by a photon



Model of a matter-antimatter annihilation event

Production of a matter particle, along with its corresponding antimatter

EXPLAIN IT TO A FRIEND

1. SCIENCE ON A TINY SCALE

Quantum physics describes the behaviour of very small things, like electrons and atoms. That's why we don't notice weird quantum effects in everyday life. But quantum physics explains how atoms and molecules work, including molecules like DNA. We need quantum physics to do everything from designing computer chips to genetic engineering.

2. EVEN EXPERTS GET CONFUSED

At the quantum level the distinction between waves and particles is blurred. Everything in the quantum realm is both wave and particle at the same time. Experiments designed to measure waves find waves, while experiments designed to measure particles find particles. What you look for is what you get.

3. PROBABILITY IS KING

Probability rules in the quantum world. If a single quantum entity, such as an electron, has a 'choice' of options, such as which of two holes to go through, it chooses at random. Einstein hated the idea that 'God plays dice', and did not accept this. But experiments show he was wrong.

together and fuse, then combine with other particles to make nuclei of helium. The helium has less mass than the particles that went into it, so energy is released in line with Einstein's famous equation, $E=mc^2$. Astronomers are able to figure out how hot the interior of the Sun must be in order to hold itself up against gravity.

But this then led to a puzzle. Because protons are positively charged, they repel each other and have to be moving very fast before they will collide and stick together. Classical physics said that the interior of the Sun is not hot enough for this to happen. Quantum physics provided the explanation. When two protons are close together, but not close enough to touch according to classical theory, quantum uncertainty means that there is a probability that they might actually touch. Another way of understanding this is to think of the protons as waves, reaching out to each other. Either way, the result is that the protons can fuse. They are said to tunnel through the barrier of classical electrical repulsion.

What is antimatter?

One of the strangest predictions of quantum physics is that for every type of particle, there should be an antiparticle that has its key properties reversed. The electron, for example, has a negative charge, while its antiparticle, the positron, has positive charge.

The physicist Paul Dirac was the first person to take this seriously, but when he published the idea in the 1920s he cautiously suggested that the required positive particle might be the proton, the only other particle known at the time. But in 1932 the physicist Carl Anderson discovered the tracks of positively charged particles with the same mass as electrons in a device known as a cloud chamber. This breakthrough earned him a Nobel Prize.

Dirac had been more correct than he had realised himself. It turns out that particle-antiparticle pairs (such as an electron and a positron) can be made out of pure energy in line with Einstein's equation, but when a particle and its antiparticle meet they annihilate each other in a puff of gamma rays. ■

DR JOHN GRIBBIN is a science writer and astrophysicist

Find out more Listen to an episode of *The Infinite Monkey Cage* about quantum physics at **bit.ly/monkeycage**

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Quantum physics gives us free will! Without it you would have no choice about anything. It explains what life is and how my phone works.

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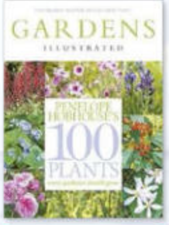
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THE FUTURE OF GADGETS

TECH HUB

EDITED BY **RUSSELL DEEKS**

THIS MONTH

APPLIANCES OF SCIENCE
Brain zappers, robots, smartwatches and more
p89

ULTIMATE TEST
The best technology to secure your home this summer
p90

ON THE HORIZON

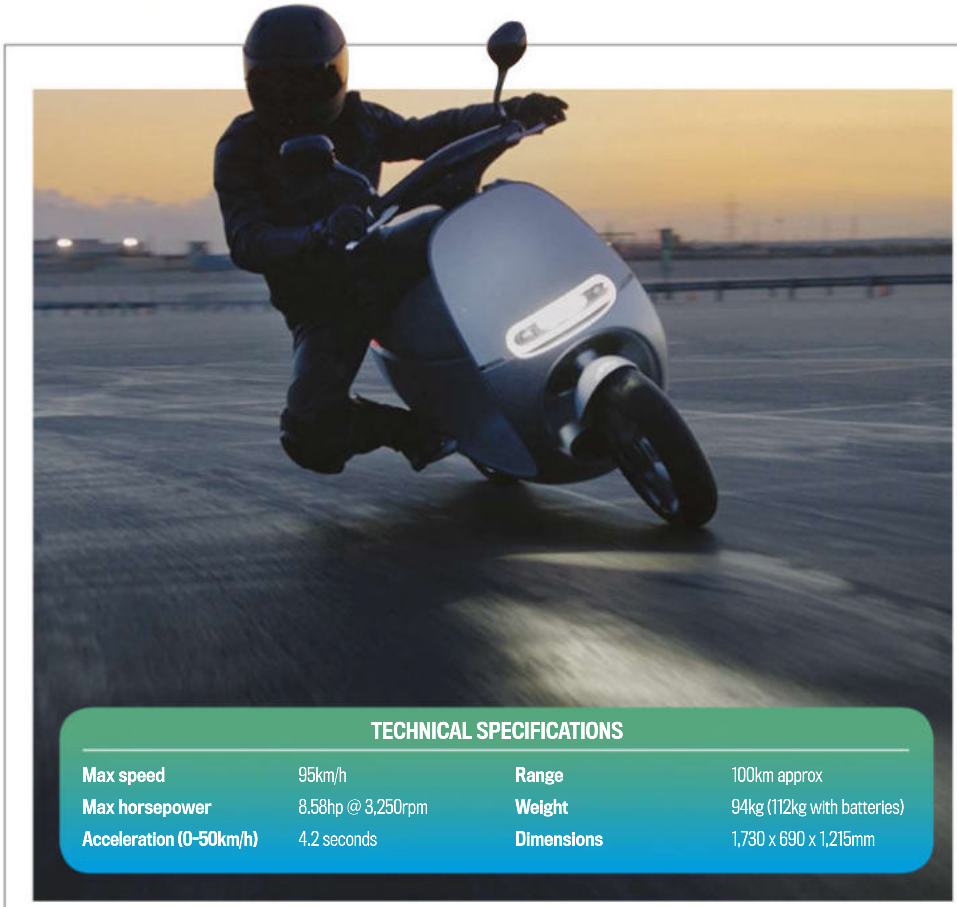
GOGORO SMARTSCOOTER

A zero-emissions scooter you'd actually want to be seen on
gogoro.com

THE GOGORO WAS unveiled at the Consumer Electronics Show in Las Vegas in January, and it might just be the future of urban transport. The Gogoro Smartscooter isn't the first electric scooter by any means, but its sleek, stylish looks and innovative swappable battery system make it the mostly hotly tipped model right now. It's also the first that's been specifically designed to address the transport needs of denizens of 'megacities' – that is, cities with a population of over 10 million.

Two entrepreneurs called Horace Luke and Matt Taylor, whose backgrounds lie not in the automobile industry but in consumer electronics, founded Gogoro in 2011. Both Luke and Taylor previously worked at Microsoft and HTC, while their individual CVs include the likes of Motorola and Nike. Gogoro has received over $150m in funding from investors including HTC founder Cher Wang, while a key partner is Panasonic, which has helped to design the Smartscooter's unique battery/charging system.

It's the innovation in this area that makes the Smartscooter so interesting. With most



TECHNICAL SPECIFICATIONS

Max speed	95km/h	**Range**	100km approx
Max horsepower	8.58hp @ 3,250rpm	**Weight**	94kg (112kg with batteries)
Acceleration (0-50km/h)	4.2 seconds	**Dimensions**	1,730 x 690 x 1,215mm

With a top speed of 95km/h (60mph), the Gogoro is nippy enough to cope with commuter traffic

PHOTO: GOGORO

→ electric vehicles, around 40 per cent of the purchase cost simply pays for a large battery that requires regular charging. Not so with Smartscooter: instead, you buy the bike outright for the price of £2,600, then lease charged batteries from 'GoStations' located all across the city, much as you buy a mobile phone handset outright and then lease airtime from a network provider. When your batteries – they come in pairs – start to run low, you simply pull up at the next GoStation and exchange them for a fresh pair.

The benefits in terms of keeping you moving are obvious, but there's more to Gogoro's power system than that. There are 30 sensors on the bike itself and 25 in the battery, all connected to the cloud and a smartphone app. They monitor everything from average speed to your riding position. That way, when you want to swap batteries, the GoStation knows whether you're a speed merchant who's definitely going to need that fully charged, brand new cell, or a cautious commuter type for whom an older battery that's only 85 per cent full will do just fine. The same sensors will also alert you if any part of your Smartscooter needs attention, reducing the likelihood of mechanical failure and improving safety.

You can only withdraw a fresh battery from a GoStation after you've put a dead one in first, and each battery 'loan' is centrally recorded – so if anyone should steal your Smartscooter, their whereabouts will be instantly known the next time they try and put in new batteries. Each pair of batteries will give you a range of around 100km (60 miles) from fully charged, and batteries will be withdrawn after 500 charging cycles – the point at which capacity starts to drop significantly – to be re-used in data centres, homes and offices. Then, towards the end of their life, they'll be donated to charity projects in developing nations.

Taipei in Taiwan is the world's first city to be kitted out with a full city-wide network of GoStations, and the first Smartscooters will go on sale there this summer. After that, Gogoro has plans to roll out its Energy Networks across Asia, Europe and the US. The future success of the Smartscooter remains uncertain, of course, but just look at the thing: if we're ever going to ride off into a zero-emissions sunset, then that's the two-wheeler we want to do it on.

RUSSELL DEEKS is a freelance science and technology journalist

TECHOMETER

WHAT'S HOT

STEAM MACHINES

There have been plenty of false starts along the way, but it now looks like the first Steam machines – console-like PCs that run Valve's gaming-orientated SteamOS and are designed to sit below your TV – should finally be in stores before the year's out. First off the blocks will be the Alpha from Alienware, and the Steam Machine I from Cyberpower, both priced at around £400.

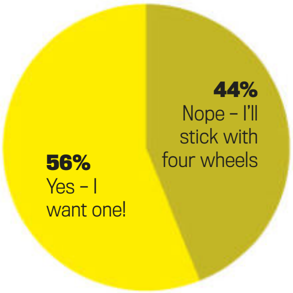
WHAT'S NOT

LASTPASS

If your entire business model is based around keeping people's passwords safe, then having your own databanks compromised by hackers is pretty much the worst disaster that could befall you. Yet that's exactly what happened to online passport manager LastPass back in June, with the company urging all users to change their master passwords as a result. You had one job, LastPass...

READER POLL

Does the Gogoro inspire you to leave the car at home?



THE NEXT BIG THING

SURVEILLANCE STATES

Music fans had their faces compared to those of criminals at this year's Download

AS I WRITE this on a train, a camera is filming me and my fellow commuters. It's there for my 'safety and convenience', and it's increasingly unremarkable to be observed in this way. Soon we will have to make the assumption that we are always on camera when not explicitly in private.

Filming in public is not new, of course. CCTV cameras linked to operations rooms have been around since the 1970s, and are a common feature of the urban environment. But today's combination of high-definition cameras, fast networks, effectively unlimited storage capacity and powerful image processing algorithms is taking us into new territory, and it seems to be unstoppable.

The change was highlighted earlier this year when Leicestershire Police pointed cameras at the 90,000 people attending the Download music festival. They were using NeoFace software to look for face-matches in a database of criminals known to target music festivals, in an attempt to prevent misdemeanours at the three-day event.

The police haven't said how many people they arrested at Download. They claim that they weren't storing any images and that they destroyed the data after what they are calling a 'trial'. But whether or not they kept any pictures, and whether or not it was successful for the police, the operation gave festival-goers an early chance to experience the brave new world of total observation.

In his 1921 novel *We*, the Russian writer Yevgeny Zamyatin describes a society in which everyone is watched constantly, living in glass houses and only allowed privacy during sex. Like *Nineteen Eighty-Four*, which it influenced, it was supposed to be a dystopian fantasy, not a manual for policing.

We now have all the technical components we need to ensure that nobody goes unobserved, and the arguments against have to be made on political rather than technical grounds. In May this year Ed Snowden took part in a discussion on Reddit where he said: "Arguing that you don't care about the right to privacy because you have nothing to hide is no different from saying you don't care about free speech because you have nothing to say." This is an argument that deserves to be more widely promoted.

The irony is that the police probably didn't need to go to the trouble of setting up a scanning station – the thousands of pictures of the festival uploaded to Flickr, Google Photos, Instagram and Facebook probably provide more than enough faces to process, and without any troublesome press coverage. In fact, if you wanted to create a surveillance state, the simplest way would be just to build a free photo-sharing app and then mine the pictures for criminal intelligence.

BILL THOMPSON contributes to news.bbc.co.uk and the BBC World Service

FROM THE LAB

Instant thought-to-text conversion

WHAT IS IT?

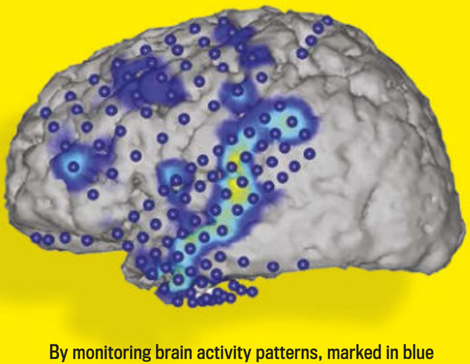
A system developed by scientists at New York's Albany Medical Center and Germany's Karlsruhe Institute of Technology that detects brain activity in areas of the brain linked to speech, and translates that information back into words.

HOW DOES IT WORK?

Electrodes that measure electrical activity are applied directly on the surface of the front half of the brain. The signals detected are compared to known signals for different sounds like 'sh' or 'ah'. The system then builds words phonetically. Over time, an algorithm learns to avoid mixing up similar words, such as 'where' and 'wear'.

WHAT WOULD THE TECHNOLOGY BE USED FOR?

Although the technology is still in its very early stages – and only around 50 to 75 per cent accurate – it's hoped that eventually it could provide a means of communication for patients with locked-in syndrome. It could also be used in advanced computer interfaces.



By monitoring brain activity patterns, marked in blue and yellow, spoken words can be recognised

PHOTO: PRESS ASSOCIATION

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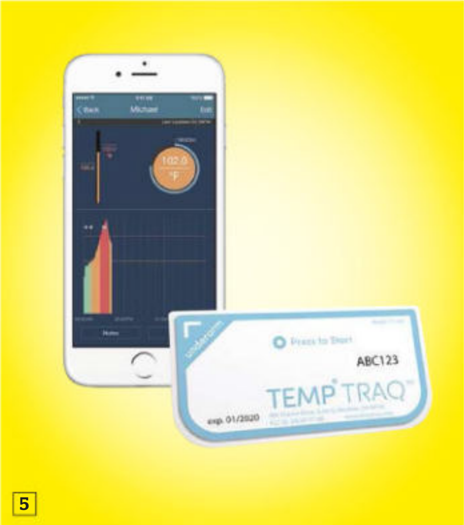
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APPLIANCES OF SCIENCE

1 BRAIN BOOSTER

Want to pep yourself up ready for a busy day – or wind down after one? Try zapping your brain! The Thync system combines an app and headpiece to bombard your neurones with low-level currents that Thync calls 'Vibes'. You can choose from 'Calm' or 'Energy'. The tech involved is used by neuroscientists, but some have expressed concern about its use by non-specialists outside the lab.

Thync
$299 (£193 approx),
thync.com

2 CHATTER BOT

Meet Musio, a cute, artificially intelligent assistant. Originally designed to help kids learn languages, Musio talks to you, answers questions, tells jokes and manages your diary. If you add the optional Bluetooth unit, it can control your smart devices – and the more you interact with Musio, the more it learns. Musio has smashed its $50,000 Indiegogo target and will ship in 2016.

Musio
From $99 (£64 approx),
bit.ly/Musiobot

3 LONG-LIFE LIGHTING

His father James transformed vacuum cleaners, fans and hand dryers, and now British inventor Jake Dyson has turned his attention to the desktop lamp. His CSYS dimmable lamp is adjustable in three axes and applies technology used in satellites to disperse heat from its LED bulbs – with the result, claims Dyson, that they'll last for 37 years. The catch? That price tag…

CSYS Lamp,
£399,
www.dyson.co.uk

4 WATCH THIS

If smartwatches from Apple et al aren't floating your boat, design your own! The Blocks modular watch, which will launch a crowdfunding campaign this summer, features a core unit housing an e-ink screen, processor, motion sensor, Wi-Fi and Bluetooth. You can add modules from a line-up that includes a heart monitor, NFC chip, extra battery, mic, GPS, camera, USB memory stick and more.

Blocks Smartwatch
Price TBC,
chooseblocks.com

5 BABY MONITOR

All parents will know the anxiety that comes with having a child who's poorly. TempTraq aims to ease your worries. This wireless, continuously monitoring thermometer adheres to your little one's skin like a large sticking plaster, and sends information about their temperature to your iOS or Android device via Bluetooth. The patches are waterproof, and each lasts for 24 hours once activated.

TempTraq
$25 (£16 approx),
temptraq.com

6 WRIST PROTECTOR

Who wouldn't want to swap their boring mouse for a robot head that projects a mouse interface onto the desk? The Odin Aurora is no mere toy, though. Around 4 per cent of the population will suffer at some point from carpal tunnel syndrome – pain in the hands and arms that can be caused by the motions involved in using a mouse. With Odin, smaller movements mean less chance of injury.

Odin Aurora
$69 (£45 approx),
serafim-tech.com

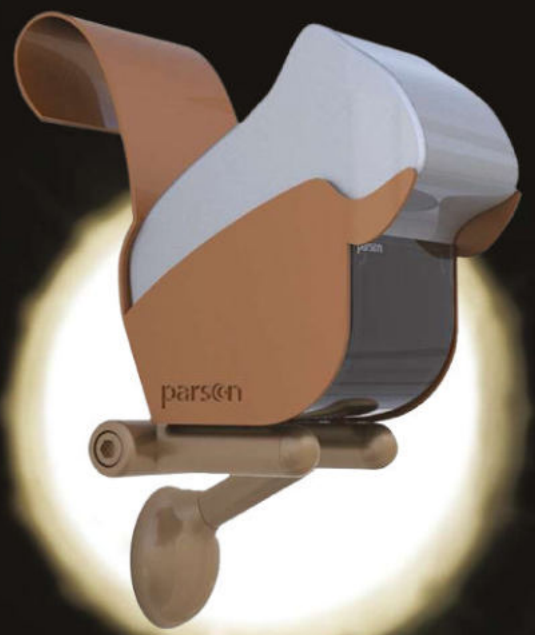
STOP! THIEF!

Protect your home and family from thieves and wrong-doers with these high-tech security systems

CANARY

$249 (£158 approx), canary.is

CANARY IS ONE of several systems – see also setups from Piper and iSmartAlarm – that offer affordable home monitoring via an accompanying app on your smartphone, with no monthly subscription. Its body houses motion, temperature, humidity and air quality sensors, as well as a mic and wide-angle HD video camera with infrared night vision. Over time, these sensors learn what is 'normal' for your household, and will alert you if anything seems awry.



PARSON ANIMALS

Price TBC, parson.it

DESIGNED TO BLEND unobtrusively into the most stylish surroundings, the Animals range of security cameras can be installed indoors and out. Made from recyclable materials, the different models (chameleon, owl, cricket, 'urban bird' and so on) are all based around the same HD video camera and MicroSD card slot, but advanced features such as face and number plate recognition, panic detection and 'people counting' vary from model to model. They're available to pre-order now.

PHOTO: ISTOCK

YALE KEYFREE CONNECTED SMART LOCK

£500, yale.co.uk

THERE'S NO SHORTAGE of 'smart' locks that let you open your front door with your phone. But this one comes from the grandaddy of lock design, Yale, and uses the Z-Wave home networking protocol. That means the same app that lets you into the house also gives you remote control of a range of over 1,000 smart appliances (including lighting, window blinds and more) from wherever you happen to be.

OLA

From $119 (£75 approx), bit.ly/ola-lock

WE'VE BEEN USING keys since the first millennium BC, while the first keycard lock was patented in 1975. Doesn't your high-tech home deserve a security system that's a little more up-to-date? Enter Ola, which grants you instant keyless, cardless entry via state-of-the-art fingerprint recognition. It's currently seeking Kickstarter funding and can store and recognise up to 1,700 prints. Bluetooth and an accompanying smartphone app mean you can still grant temporary access to others if you need to.

NETATMO WELCOME

€199 (£140 approx), netatmo.com

YOU KNOW WHO'S welcome in your home and who isn't... and so does this Full-HD video camera, which is equipped with infrared night vision, a 130° field of view and facial recognition software. Welcome sends a message to your iOS/Android device when anyone enters your house – either putting your mind at rest because the kids are home safely, or letting you know it's time to call 999 – and its footage is stored in the camera rather than in the cloud, to keep you safe from hackers.

FAKETV

£25, responseelectronics.com

BURGLARS GENERALLY WANT to avoid confrontation. A lighting timer is one way of convincing would-be intruders that your empty property is occupied, but this LED unit that mimics light coming from a television is an alternative. The flickering LEDs realistically simulate scene changes and fades, and it automatically powers on at sunset. FakeTV only consumes about as much electricity as a children's night light, making it safer, greener and cheaper than just leaving the telly on.

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Welcome your guests and deter potential intruders with this highly effective motion activated 'dusk til dawn' solar spotlight. This all-in-one no wiring required light, turns on automatically at night when motion is detected by the PIR sensor and switches itself off after one minute. During the day sunlight charges the solar panel on top of the light, ready for use when the sun goes down. So simple to install – everything is included – simply stake into the ground or attach to a wall (both kits supplied), with no messy or complicated wiring required.

With 12 ultra-bright LEDs which provide up to 8 hours of light on a full charge (if there's constant motion), plus it even features a flashing red light that simulates a home security system. 4xAA rechargeable batteries included.

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PICK OF THE MONTH

Thar she blows... but will the whales be blowing on cue this August?

Big Blue Live

MONTEREY BAY IS a magnet for wildlife spotters. Every year, a maelstrom of marine life whips up this section of Californian coast: blue whales, humpback whales, elephant seals, sea lions, dolphins, sea otters and great white sharks. It's the mother of all foam parties, and to celebrate, BBC One will broadcast live from the Bay this August. Over three nights, Matt Baker, Liz Bonnin, Steve Backshall and Hugh Fearnley-Whittingstall will give viewers an up-close look at this wet and wild show.

Humpback and blue whales are drawn to the area by the massive blooms of fish at this time of year. For them, Monterey Bay is a luxury service stop on their epic migration north, complete with an all-you-can-eat buffet of fish, krill and plankton. So what are the chances of seeing a blue whale? It might be the largest animal ever to have graced our planet, but it's surprisingly difficult to spot.

"Blue whales are remarkably fast for an animal of that size, and they stay at the surface for a comparatively short time," says Steve Backshall. "They're a terrific challenge, but if you manage to film them, their sheer scale is just jaw-dropping." In a bid to catch a glimpse, the team will carry out aerial reconnaissance missions over the Bay. They'll also attempt to track the whales by applying suction cups equipped with GPS transmitters to the animals. In the process, they might uncover new information about the whales' behaviour and feeding habits.

Another highlight will be the California sea lion. "It's one of the most interactive, potentially aggressive, and joyous animals to encounter," says Backshall, who hopes to go diving with them during the show.

Today, Monterey Bay is a haven for wildlife, but that hasn't always been the case. A barrage of overfishing and overhunting up until the early 1900s very nearly proved catastrophic.

"Almost all of the native wildlife disappeared completely," says Backshall, "but thanks to fabulous conservation efforts since the end of the last century, it's made a spectacular comeback."

So, blue whale or not, we're in for a treat.

JAMES LLOYD

Big Blue Live airs on BBC One on 23, 27 and 30 August – for exact times see *Radio Times*

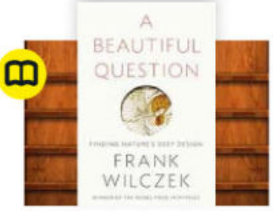
DON'T MISS!

Inside The Animal Mind

How your dog knows it's dinnertime, and the corvid *Krypton Factor*. **p94**

Edinburgh Fringe Festival

There are a surprising number of science-themed shows at this year's Fringe. **p97**



A Beautiful Question

Nobel Prize-winning physicist Frank Wilczek explores symmetry in the natural world. **p98**

PHOTO: BERTIE GREGORY/NATUREPL.COM/BBC

WATCH

TV & ONLINE

WITH JAMES LLOYD

FROM **26** JULY

NASA's Unexplained Files 2

Discovery Channel, 8pm

Seth Shostak, Director of SETI

SOMEWHERE IN NASA'S vast archives – probably in a dusty file marked 'TOP SECRET' – sits a whole collection of strange and sometimes inexplicable stories. Could huge spider-like formations on Mercury be evidence of alien life? Did NASA accidentally nuke Jupiter? Did the Nazis win the Space Race? Probably not, but it's fun to speculate, right?

10-14 AUGUST

Jungle Babies: Tarsier Tails

Eden, 6pm

Go on, try not to say 'aaaw'...

WITH ITS DINNER-PLATE eyes and tennis ball size, the tarsier is undoubtedly one of the cutest animals on the planet. Unfortunately, it's also one of the most elusive. So when given the chance to watch two families of these nocturnal ninjas frolicking and gambolling in their natural Indonesian habitat, how could anyone possibly resist?

17 AUGUST

Megastructures: Mega Tanker Makeover

National Geographic Channel, 8pm

How to recycle an oil tanker

HOW ABOUT THIS for an extreme makeover? The Pioneer is a 17-year-old oil tanker which, with the help of $600m (£391m) , is being converted into a state-of-the-art floating oil rig. If the project succeeds, it'll be the very first floating rig in US waters and bolster the country's rapidly disappearing reserves of oil – but not everyone thinks it's a good idea.

JAMES LLOYD is the editorial assistant at *BBC Focus Magazine*

PHOTO: BBC, ALAMY, DISCOVERY CHANNEL, UKTV/BBC

Chris Packham investigates animal intelligence

18-20 AUGUST

Inside The Animal Mind

Eden, 9pm

WE HUMANS HAVE the habit of projecting human characteristics onto the animals around us. Foxes are invariably sly and crafty; owls are wise; cats are either contented furballs or screeching divas. That's the folklore version, anyway – but what's really going on inside their minds?

Here's another chance to see Chris Packham's excellent three-part series, first shown on BBC Two last year. Wondering how your pooch sees the world? Chris reveals how a dog's sense of smell gives it a bizarre alternative reality – possibly even enabling it to gauge what time of day it is by monitoring the scent levels of its owners as they go about their daily routine.

Meanwhile, in the Bahamas, Chris gets up close with a pod of dolphins, finding out how they communicate with each other to establish an underwater society. He visits an aquarium to test whether dolphins really can recognise themselves in a mirror – a feat that was once thought to be limited to humans.

Most impressive of all are Chris's forays into the bird world, where he explores the minds of some of the cleverest problem-solvers on the planet: crows. He sets up an eight-step challenge involving sticks, stones, trapdoors, cages and a tasty treat. It's probably the most complex animal puzzle ever devised, and yet the crow doesn't miss a beat. Birdbrain, you say? Pah!

NEW FROM FOCUS

Do you want to live a longer, healthier and happier life? Of course you do... and here's a *BBC Focus* guide to doing just that. Our experts looked at the most up-to-date research and weighed up all the evidence to bring you **the definitive manual for living well in the 21st Century**. Find out:

- How **medicines** and **vaccines** have tamed previously fatal diseases
- Why many Western doctors now recommend **yoga** and **meditation**
- The truth about **caffeine**, sugar, red meat, **salt** and so-called '**superfoods**'
- How **bionic implants** and **robot nurses** are transforming healthcare

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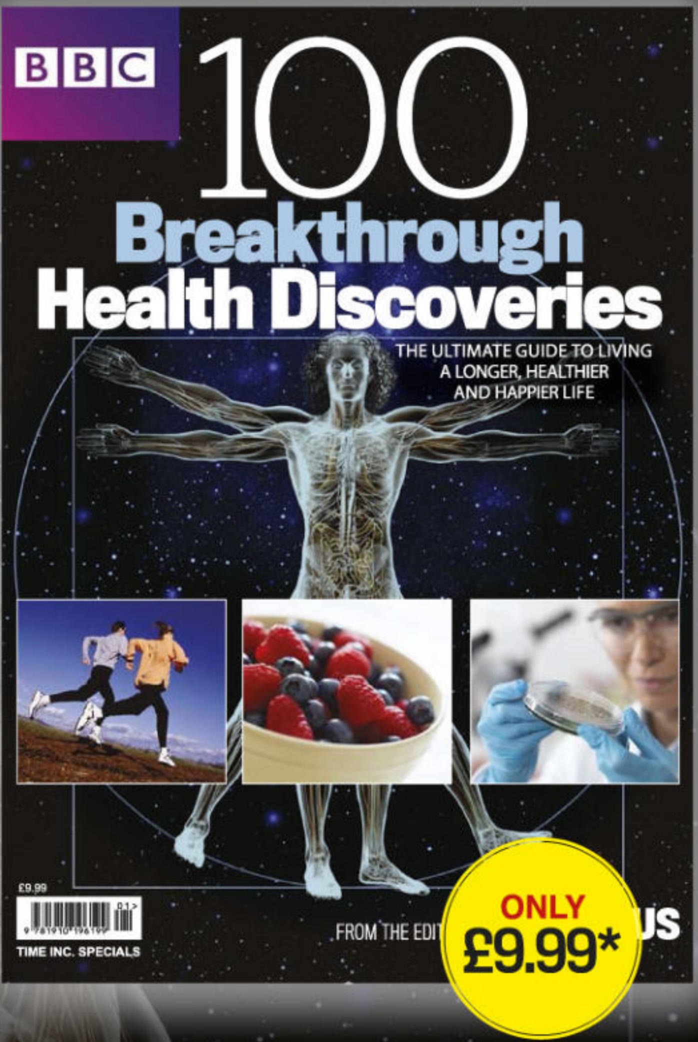

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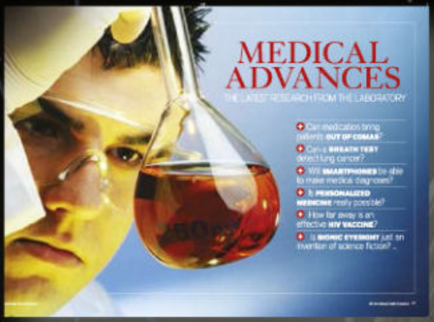

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Discover the startling new advances still being made in medicine today

14 Running on empty

The UK's top sports scientists help you get the most from your exercise regime

50 Free your mind

51 View your glass as half-full

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LISTEN

BBC RADIO PROGRAMMES

WITH JAMES LLOYD

23 JULY

Elements: Technetium

BBC World Service, time TBC

TECHNETIUM IS ONE of the more obscure elements in the periodic table. Radioactive and short-lived, it's essential for medical imaging, yet it can only be produced in the lab. Justin Rowlatt tells the story of this mysterious metal, meeting the scientists who milk technetium 'cows' to save lives.

25 JULY

Heart And Soul: Belief In Silicon Valley

BBC World Service, time TBC

WHAT HAPPENS WHEN the worlds of technology and religion collide? Peter Bowes travels to California's Silicon Valley to meet some of the high-achieving, high-earning technologists who've embraced religion. How do they marry their faith with the seemingly secular world of bits and bytes?

Silicon Valley: is there any room for faith?

11 AUGUST

The End Of The Body Mass Index

BBC Radio 4, 9pm

TAKE YOUR WEIGHT in kilograms and divide it by the square of your height in metres. *Et voilà*, your body mass index – but how useful is it? Dr Mark Porter asks whether it's time to switch to more useful measures.

Dr Mark Porter questions the use of BMI

17 AUGUST

Discovery: Women In Science

BBC World Service, times TBC

ACCORDING TO UNESCO data, only 30 per cent of the world's scientists are women. At 38 per cent, the UK is slightly above average, but we still have a way to go. UK women actually outnumber men in university science degrees, so why are so few pursuing careers in research?

ONLINE

The Living World

bbc.co.uk/programmes/b007qyz3

CHRIS PACKHAM LOOKS back through nearly 50 years of *The Living World* archives. Revisited episodes include 'The Mayfly And The Chalkstream' – a beautifully bucolic look at the life of a mayfly – and 'The Stag Beetle Hunt', which shines a light on this most formidable of insects.

TOUCH

SMARTPHONE & TABLET APPS

WITH KATE RUSSELL

Elements 4D

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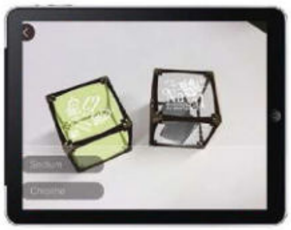
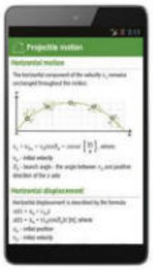


CHEMISTRY SETS CAN be dangerous, but you can ignite an interest in science without blowing up the kitchen if you use *Elements 4D*. After printing out and constructing six paper cubes with different elements represented on each side, you bring them to life using the augmented reality viewer. Each image reveals a glass box containing a sample of the element. Pick a cube up and turn it around to examine its contents, or bang cubes together to cause chemical reactions to occur – only with far less risky consequences for the curtains.

Pocket Physics

Android, Geckonization, free



PHYSICS STUDENTS AT all levels can now take some of the strain off their memories thanks to *Pocket Physics*. This Android app is really a nicely designed reference book – although the flashing and interstitial ads are an annoyance, and it would be much better if there was the option to pay to get rid of them. There are no interactive multimedia bells, just straightforward facts, arranged in a way they are easy to access. If you ever happen to find yourself in a field with an urgent need to know the formula for measuring kinetic energy, you'll be glad to have this in your pocket. Or at least you will be, once you've swiped to get rid of the advertising screens...

Gene Screen

iOS 4.0 or later, iPhone/iPad/iPod Touch, Cold Spring Harbor Laboratory, free

IF YOU LIKE a little razzmatazz with your science, *Gene Screen* offers a fun and interactive way to learn about genetic science. Well, 'fun' might not be the right term to use when talking about studying inherited diseases and how certain afflictions are more prevalent in different populations, but the short animations and memorable graphics do make this complex topic easier to grasp. There's also information on recessive genes and genetic screening programmes if you want to take your research further. A great resource for biology students.

KATE RUSSELL is a technology journalist and BBC *Click* presenter

PHOTO: BBC, ISTOCK X2, FOYLES, JOHN HINTON

VISIT

EVENTS & EXHIBITIONS

WITH JHENI OSMAN

29 JUNE - 9 AUGUST

Light! Camera! Action!

National Museum of Scotland, Edinburgh, 12pm-4pm, free, nms.ac.uk

BUILD A SIMPLE camera, experiment with heat and light, and discover the science behind photographic processes at this exhibition.

25 JULY - 30 AUGUST

Foyles Summer of Fun

Foyles stores, Bristol and London, foyles.co.uk/events

ONE FOR THE big kids among us! *Star Wars*, *Minecraft* and Aardman characters come alive in science-themed screenings, performances and workshops at Foyles stores.

6 AUGUST

Silver Screen Sci-Fi: THX-1138

Royal Observatory Greenwich, London, 7pm-9pm, £8, rmg.co.uk

CHOW DOWN ON popcorn while watching George Lucas's lesser-known sci-fi classic, *THX-1138*, set in a dystopian future in which mankind's emotions are controlled by forced medication.

7 AUGUST - 1 NOVEMBER

Secret

Science Gallery, Dublin, free, dublin.sciencegallery.com

CODERS AREN'T JUST computer nerds. At this exhibition, discover how code is used in encryption and hacking, but also appears in the beautiful mathematical structures seen in nature.

8-9 AUGUST

MakeFest

Museum of Science and Industry, Manchester, free, mosi.org.uk

KNIT A MOLECULE, create some code or get baking. This festival is for those who love crafting, tinkering and simply geeking out.

13 AUGUST

3D Printing For Adults

Royal Institution, London, 10am-4pm, rigb.org

SAVE A FEW hundred quid splashing out on a 3D printer on a let's-get-creative whim, and enrol on this 3D printing workshop instead.

After previously playing Einstein, John Hinton treads the boards as Marie Curie

EDITOR'S CHOICE

7-31 AUGUST

Edinburgh Fringe Festival

Various venues, Edinburgh, edfringe.com

IF YOU'VE NEVER been to the Fringe – go! There are loads of science-themed events such as Alas, Poor Darwin; Am I Dead Yet?; Frankenstein; and Quantum Magic. 2015 seems to be the year to celebrate female scientists too. Ada is a show that delves into Ada Lovelace's life as the first computer programmer, while musical comedy The Element In The Room follows Nobel Prize winner Marie Curie's real-life journey across America to find a single gram of radium so she can continue her research.

17 AUGUST

A Night In The Jungle

Natural History Museum, London, 12:30pm-1pm, 2:30pm-3pm, free, nhm.ac.uk

AT THIS TALK, hear about the adventures of scientists tasked with collecting moths from around the globe.

UNTIL 24 AUGUST

Biosense

Museum of Natural History, Oxford, www.oum.ox.ac.uk

DISCOVER HOW LIGHT affects our behaviour, how oxygen sensing could revolutionise medicine and how bacteria detect their world.

UNTIL 6 SEPTEMBER

Artatomy

Life Science Centre, Newcastle, life.org.uk

AT THIS EXHIBITION, check out intriguing artworks by medical students who take their inspiration from anatomy.

READ

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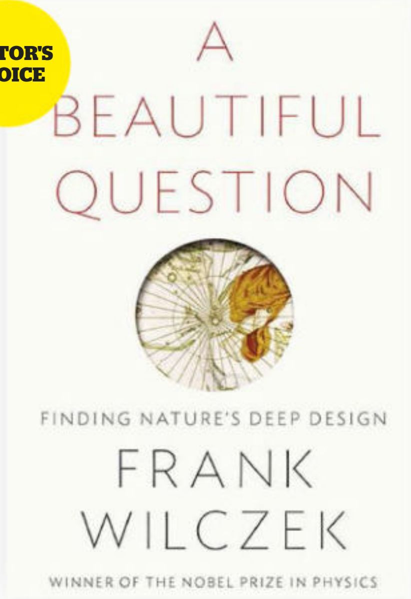
A Beautiful Question

Finding Nature's Deep Design

Frank Wilczek

Allen Lane H £20

EDITOR'S CHOICE



A BEAUTIFUL QUESTION

FINDING NATURE'S DEEP DESIGN

FRANK WILCZEK

WINNER OF THE NOBEL PRIZE IN PHYSICS

DOES THE WORLD embody beautiful ideas? In these days of global turmoil and seemingly endless reports of misery, atrocity and death, a natural response would be: "Are you joking?"

Even if everything was just fine, such questions do come across as a bit academic. Sure enough, the author of *A Beautiful Question* is an academic. More surprising, perhaps, is the fact that Frank Wilczek is a professor of theoretical physics, whose practitioners are notorious for having little patience with airy-fairy philosophical issues.

But Wilczek is no ordinary physicist. In 1973, at the age of just 21, he and his doctoral advisor David Gross at Princeton University made a major discovery about how the Universe is put together. Roughly speaking, they showed that the nuclei of atoms are held together by a bizarre force that gets stronger with distance. In the process, they explained why quarks – the building blocks of matter – are trapped inside protons and neutrons, and won a share in 2004's Nobel Prize in Physics.

What Wilczek argues he really found, however, is evidence that the world (by which he means the entirety of creation) embodies beautiful ideas. To back his claim, he's pulled together his thoughts into what he calls "a long meditation" on the subject.

And *A Beautiful Question* is just that: over 300 pages, plus a 60-page glossary, and artwork illustrating everything from Platonic solids to yin and yang.

This may all sound a bit hippy-dippy, and some readers may see parallels with two bestsellers from the 1970s, *The Tao Of Physics* by Fritjof Capra and *The Dancing Wu Li Masters* by Gary Zukav. Both claimed to have uncovered connections between quantum theory and New Age ideas about consciousness and the cosmos.

Be warned: Wilczek is no hippy. His exploration of parallels between concepts from art, like symmetry and projective geometry, and those from high-energy physics are sophisticated and, frankly, often pretty opaque. Even experts in relativity may never have twigged that, as Wilczek puts it, "gravitons are the avatars of general covariance".

It's rare that scientists as brilliant as Wilczek give us a glimpse of what goes on inside their heads. Anyone taking up this opportunity should expect to come away pretty dazzled.

■■■□□

> **"It's rare that scientists as brilliant as Wilczek give us a glimpse of what goes on inside their heads"**

ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham

MEET THE AUTHOR

Frank Wilczek

Why did you decide to write a book about beauty?

The seed was planted several years ago when I was asked to give a lecture on 'quantum beauty' at Cambridge University. I was inclined to turn it down at first, because it seemed so outlandish. But I found the idea really growing on me – it brought me back to the kinds of philosophical questions I was obsessed with as a teenager. The lecture was very well-received, and I've discovered more and more that if you poke underneath the surface, beauty is a big part [of physics].

Beauty is very subjective, so how do you define it?

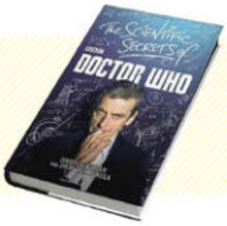
In common usage, beauty has many subjective elements – a lot of our perception of beauty has to do with the human body and things that are emotionally resonant. But there are certain forms of beauty that we find represented in the fundamental ways the world works. In particular, these are ideas about symmetry, colour, shape, and building complicated structures from a few simple elements.

So is there a lot of symmetry in the Universe?

Symmetry is what runs the world. In physics, the fundamental equations that govern the Universe – the Standard Model – allow enormous ranges of transformations without changing their consequences. That's what we mean by symmetry of equations. In the 20th Century, it became such a dominant theme that we started with symmetry and used that to guess the equations. That's really how we got the theories of both the strong and the weak [nuclear] interactions.

MORE ON THE PODCAST

Listen to the full interview with Frank Wilczek at sciencefocus.com/podcasts



The Scientific Secrets Of Doctor Who

Simon Guerrier and Dr Marek Kukula

BBC Books H £16.99

THE PRIMARY REASON behind the phenomenal success of *Doctor Who* is good writing. Simon Guerrier and Marek Kukula's splendid volume illustrates this fact admirably by splicing together a collection of new *Doctor Who* short stories with their own supplementary chapters reflecting the current scientific thought behind each tale's themes – the 'sci' that underpins the 'fi', if you like. The book is divided into 'Space','Time' and 'Humanity' sections, which pretty much has all bases covered.

One of the joys of *The Scientific Secrets Of Doctor Who* is that you can dip in and out like a Time Lord skipping through time and space. Throughout, there's also a good smattering of facts about the show itself. It's an excellent blend of popular science and popular culture, it's cleverly structured, and is a great example of how science and fiction ultimately spring from the same creative well. It's an obvious no-brainer for hardcore Whovians, a no-brainer for anyone wondering what all the fuss is about, and a good 'beside the bed' book for people who are, like me, loitering somewhere in the middle.

■■■■□

DALLAS CAMPBELL is BBC presenter who recently fronted *Britain Beneath Your Feet*

Why Information Grows

The Evolution Of Order, From Atoms To Economies

Cesar Hidalgo

Allen Lane H £20

HERE, CESAR HIDALGO from MIT teaches us to view economies through the lens of information theory. He starts by explaining what information really is and goes on to explain how so much of it can exist in perfect order, despite the march of entropy pulling everything in the Universe towards disorder.

Throughout the book he introduces and explores many interesting and convincing concepts and arguments. Among them are 'the product space', a network used to examine how different products are related to one another within an economy, and the 'personbyte', the hypothetical maximum amount of knowledge that one individual can possess. These concepts highlight the importance of large networks of individuals in performing the complex tasks and processes occurring around us.

Unfortunately, these fascinating ideas are dulled by fairly repetitive writing. The concepts in this book are clearly valuable, and most people would find something new and exciting here. But as I'm sure the author would agree, the packaging of ideas can often be as important as the ideas themselves.

■■■□□

TOBIAS JOLLY is a statistician with an MSc in biochemistry

Rainbow Dust

Three Centuries Of Delight In British Butterflies

Peter Marren

Square Peg H £14.99

FROM THE VORACIOUS naturalists who once hunted and pinned vast butterfly collections to today's army of citizen scientists mobilised in the name of conservation, our changing relationship with butterflies tells us much about the way science has evolved. Peter Marren's book is a celebration of the role that butterflies play in our imagination and cultural lives, examining our enduring fascination for a group of invertebrates that has inspired artists and writers. While this is not a book on the hard science of butterflies, it does include intriguing discoveries and theories.

A captivating chapter on female butterfly enthusiasts explains how their scientific aspirations were often restricted to the nurturing of butterflies; another looks at the eccentricities of both common and scientific naming of species. We have had butterfly extinctions in Britain, unlike mainland Europe, and the book warns that species like the high brown fritillary or the Duke of Burgundy could be next without concerted action. But there is hope, as Marren explains, through our growing knowledge of butterfly ecology.

■■■■□

MATT SWAINE is a keen naturalist and the editor of *BBC Wildlife* magazine

Mindware

Tools For Smart Thinking

Richard Nisbett

Allen Lane H £20

RICHARD NISBETT'S BOOK, *Mindware*, is hard to review. From the cover blurb's overall tone, it's ostensibly a book about how the ways we think about things are often inefficient or inaccurate. *Mindware* sets out to show you how to avoid this flawed thinking and improve your rationalising and deduction skills. Technically, it could turn anybody into a real-life Sherlock Holmes.

However, there is just so much here. 'How people think' is a vast subject area, and Nisbett draws on so many disciplines (psychology, sociology, economics, philosophy and more), all of which are treated as equal (rightly or wrongly). This makes it very difficult to follow a coherent narrative or point. Nisbett is talented writer, although he can be rather self-aggrandising. What he's written is part textbook, part pop science, part personal musing, part self-help book, and probably more. It's great if you're into all that stuff, but it is tricky to keep track of what's being said and why.

■■■□□

DEAN BURNETT is a neuroscientist and comedian. He lectures at Cardiff University

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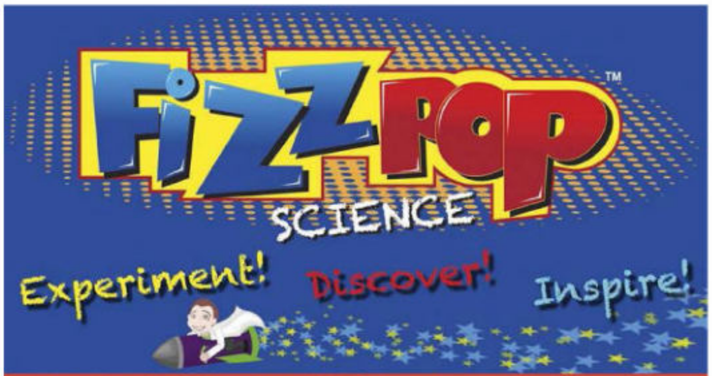
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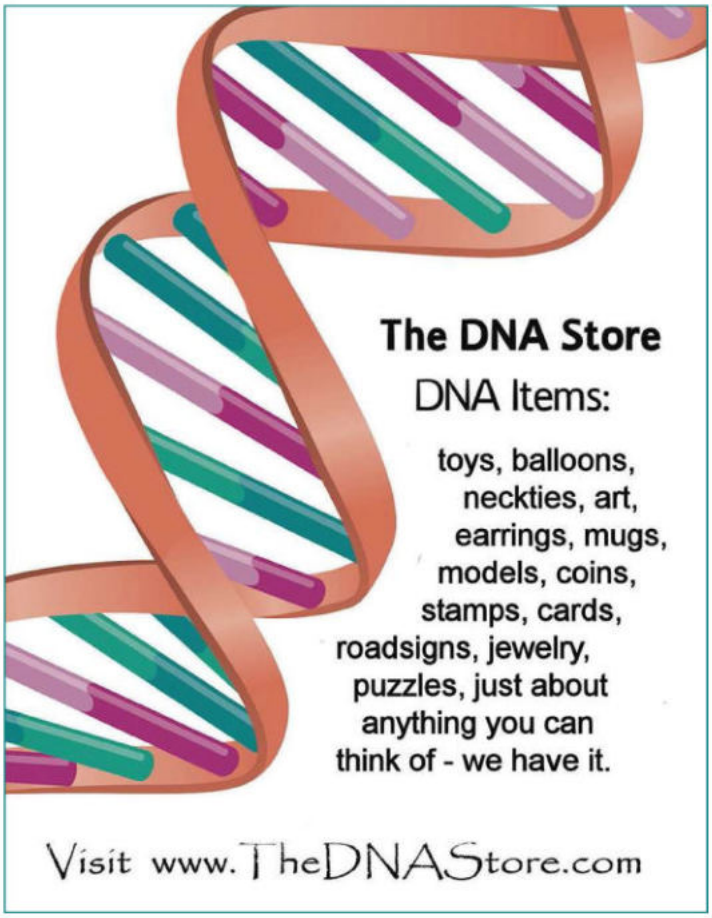
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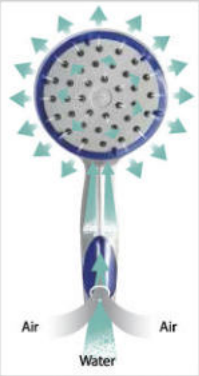

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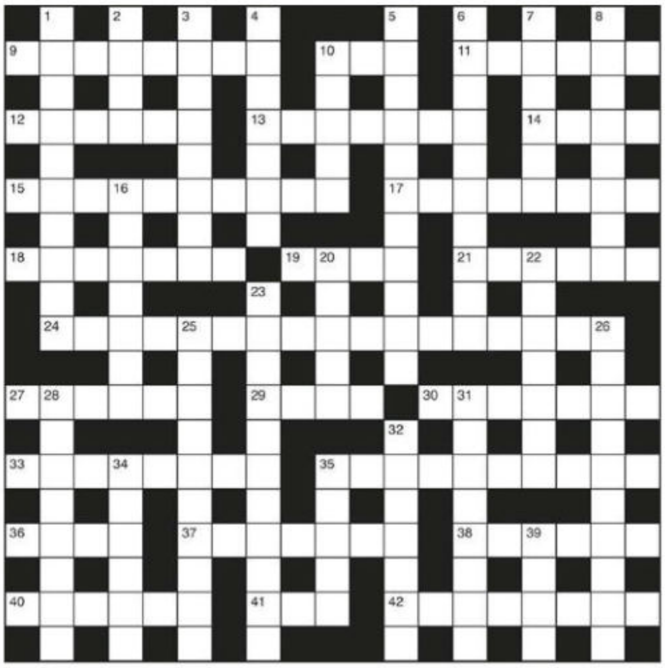
FOCUS CROSSWORD No 180

More online Solve puzzles from BBC *Only Connect* hosted by Victoria Coren Mitchell at **http://bbc.in/1vCOzuY**



ACROSS

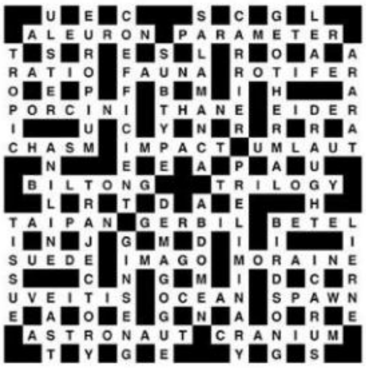
9 British artist to combine manganese ore (8)
10 Character providing pressure (3)
11 Article is definite relative to dissertation (6)
12 European then working with a fuel (6)
13 Yours truly takes subject of the forehead (7)
14 Cloudy astronomer of poor taste (4)
15 Parody edition (10)
17 Artisan caught by policeman with canine help (8)
18 Plaster forms part of stationery (7)
19 Thought aide was mad (4)
21 It is awful, getting old king to the river (6)
24 Mule's chic eminence affected by light in lab (17)
27 Lab equipment gets sharp response (6)
29 Local fellow has youngster (4)
30 Worry about party being a bore (7)
33 Sealed broadcast, then get drunk (8)
35 Permit starboard indicator to proceed (10)
36 Bird left with nothing on (4)
37 Red graduate volunteers facts first (7)
38 With small key, they activate lawn mower (6)
40 Right at home after lie to get some protein (6)
41 Very excited about whisky (3)
42 Resonant fellow follows programme (8)

DOWN

1 Calculations make him cattier, sadly (10)
2 Cat turns up with mother (4)
3 Nice seat set out for film buff (8)
4 A dimmer sort of mythological figure (7)
5 Father of medicine boxes with animal first (11)
6 Random order – it's a scotch (10)
7 Lacking in notes on nothingness (6)
8 Dutch land given to one PM (8)
10 Spike finds mine no different (5)
16 Iron construction contains food for orchestra (7)
20 Bit of training (5)
22 Divulging I like having sesame oil (7)
23 Courtesy bag distributed to smaller group (11)
25 Determined to get additive – resin – as a protective layer (10)
26 Neither has flourished in our reflection (10)
28 I'd cope – working with one school is irregular (8)
31 A cinema's arranged when he can't sleep (8)
32 Yarn about opening having space to exercise (7)
34 Mad aunt takes doctor somewhere cold (6)
35 Spirit of information, that is (5)
39 Variable answer, having to go back to philosophy (4)

SOLUTION TO CROSSWORD No 177

Margaret Baxter, Clive Roper, Steve Millard, Trudi Needham and Patricia Rutledge each solved issue 281's puzzle and receive a copy of *David Attenborough's Rise Of Animals* (Go Entertain, £8.99).



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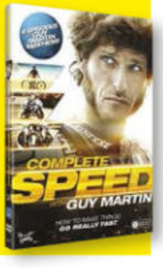

Entries must be received by 5pm on 20 August 2015. See below for more details.

YOUR DETAILS

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Post entries to *BBC Focus Magazine*, August 2015 Crossword, PO Box 501, Leicester, LE94 0AA or email a scan of the completed crossword or a list of answers to august2015@focuscomps.co.uk by 5pm on 20 August 2015. Entrants must supply name, address and phone number. Immediate Media, publisher of *BBC Focus Magazine*, may contact you with details of our products and services or to undertake research. Please write 'Do Not Contact' on your email or postal entry if you do not want to receive such information by post or phone. Please write your email address on your postal entry if you would like to receive such information by email.

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HOLLYWOOD SCIENCE

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Mind swaps in Self/less

MY DAUGHTER ASKED me what would happen if you transplanted the brain of someone who likes dogs onto the body of someone who doesn't. It raised the spectre of head transplants; a topic, some would venture, that shouldn't be discussed with a 10-year-old, much less with one who was, at the time, eyeing up the family chainsaw.

In *Self/less*, I told her, medics transfer the mind of a cancer-riddled aristocrat into the body of a young man. But the closest we've come in the real world was in 1970 when a US surgeon stitched the head of one monkey onto the twitching corpse of another. This was met with stunned silence. They didn't attempt to join the spinal cords, I explained, so the monkey was unable to move but it could breathe… for eight days until the head was rejected and the monkey died.

I stroked my daughter's hair. Things have moved on, I reassured her. William Mathews, Chairman of the American Academy of Neurological and Orthopedic Surgeons, says that "technology and pharmaceuticals have evolved to make spinal cord fusion plausible and decrease the donor-recipient rejection." And in February this year, Sergio Canavero from the Turin Advanced Neuromodulation Group in Italy described how the first ever human head transplant might happen.

> **"The head, dangling from a harness, would be manoeuvred onto the neck of the donor"**

First up, the body of a brain dead donor and the head of the recipient would be cooled to help preserve their cells. Teams of surgeons would then cut into the patients' necks, exposing blood vessels and the spinal cord. After colour-coding what connects with what, the spinal cords would be severed with an ultra-thin blade and the recipient's head, dangling from a specially constructed harness, would be manoeuvred onto the neck of the upright donor. Polyethylene glycol would then be used to fuse the spinal cord back together. With everything else reconnected, the patient would be kept comatose for around a month while jolts of electricity delivered via electrodes would help strengthen cellular connections across the once severed spinal cord. All being well, a little while later, with the help of anti-rejection drugs, the patient would wake up and be able to literally feel and move their new body. "If Dr Canavero's research breaks through the frontier of spinal cord fusion, this will be the greatest achievement in medicine of the century," Mathews says.

The Italian man is doing it because he wants to help people whose bodies are failing, I explained to my daughter. She thought for a moment, then looked at me and said, "Yes, but will they still like dogs?" ■

HELEN PILCHER is a science writer and comedian. She tweets from @Helenpilcher1

ILLUSTRATOR: TIM MCDONAGH

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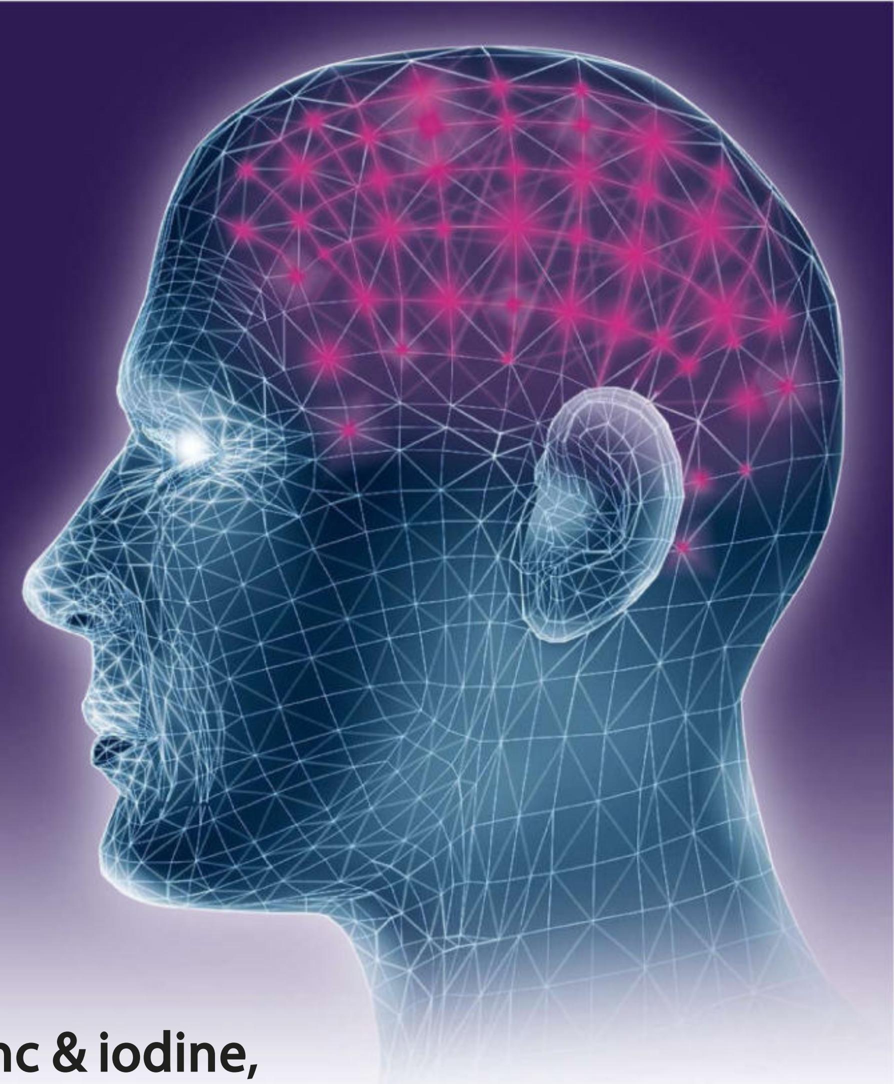

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